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THE TIROS V METEOROLOGICAL SATELLITE SYSTEM

POST-LAUNCH EVALUATION REPORT

(NASA-CR-139066) THE TIROS 5 METEOROLOGICAL SATELLITE SYSTEM Post-Launch Evaluation Report (Radio Corp. of America) 129 p

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Prepared for the

GODDARD SPACE FLIGHT CENTER
NATIONAL AERONAUTICS
AND SPACE ADMINISTRATION
WASHINGTON, D. C.

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By the

ASTRO-ELECTRONICS DIVISION
DEFENSE ELECTRONIC PRODUCTS

RCA RADIO CORPORATION OF AMERICA

PRINCETON, NEW JERSEY

AED R-2022

Issued: February 29, 1964

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PREFACE

This report contains the results of the Post-Launch Evaluation Program conducted on the TIROS V Meteorological Satellite System by the Astro-Electronics Division (AED) of the Radio Corporation of America for the Goddard Space Flight Center of the National Aeronautics and Space Administration under Contract No. NAS5-1335.

The report describes and presents evaluations of the post-launch operations and of the performance of the TIROS V satellite and its associated ground-based equipment. Recommendations for improvements in the problem areas are included.

Brief functional descriptions of the satellite subsystems and of the ground station equipment are included in this report. More detailed descriptions of the equipment and additional information concerning the design and technical development of the TIROS system are contained or referenced in the TIROS V final engineering report.

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I. INTRODUCTION

The TIROS V satellite was successfully launched from Cape Canaveral (now Cape Kennedy), Florida, on June 19, 1962, at 8:19 A.M. EST. Thirteen minutes later, the satellite was injected into a slightly elliptical orbit having an apogee of 603.7 statute miles, a perigee of 366.7 statute miles, and a calculated eccentricity of 0.02663. The orbit was inclined to the earth's equator at 58.099 degrees and the anomalistic period was 100.471 minutes.

The primary mission of the TIROS V satellite was to provide a hurricane watch during the 1962 hurricane season. The satellite carried two television cameras, one equipped with a wide-angle lens and the other with a medium-angle lens. The camera systems could be operated by ground commands, to take pictures while in contact with the TIROS ground stations, or could be programmed by ground commands, to record picture data over remote areas of the earth for later transmission to the ground stations. In addition to the television systems, the satellite carried instrumentation and electronics for telemetry and beacon transmissions, dynamics control, and attitude determination. Electrical power was supplied by a solar-energy conversion array and storage batteries. Although carried on board the satellite, the infrared detection equipment was not operational, as the result of difficulties encountered just prior to the launching.

From the day of launch until May 5, 1963 (orbit 4589), 320 days later, TIROS V provided more than 58,000 television pictures of the earth and its cloud cover. The first interrogations on orbit 001 produced pictures of excellent video quality. The satellite's wide-angle camera continued to return pictures of good to excellent quality with little or no degradation for more than ten and one-half months. Although the operational life of the medium-angle camera was short, ending on July 7 as the result of a vidicon filament failure, this camera returned pictures of good quality. The consistently high quality of the pictures taken by TIROS V is attested to by the high percentage of pictures which were useful for meteorological analysis. Of the 58,226 pictures taken, 49,236 or 84.5 percent were meteorologically useful. From these pictures a total of 1843 nephanalyses were prepared and a total of 395 storm bulletins and advisories were transmitted to weather stations throughout the world.

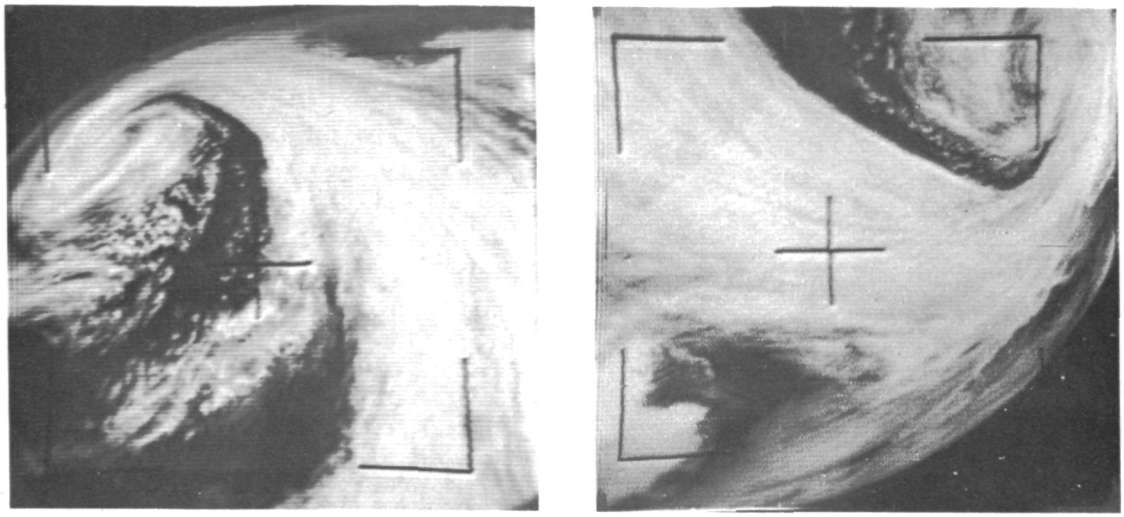
TIROS V was frequently programmed to take pictures in the latitudes where autumnal hurricanes and typhoons originate, and, in spanning the hurricane season, it provided early detection and surveillance of many of the severe weather systems during that period. Some of these systems were first detected as strong circulation centers and their paths and development into severe storms were followed continuously in the pictures returned over many orbits.

Thirteen minutes after the launching on June 19, 1962, the programmed events of satellite separation from the third-stage rocket and of satellite spin-down from the injection spin rate to the operational spin rate were confirmed by the Winkfield, England station of the Minitrack tracking network. Despite the eccentricity of the orbit, the satellite's beacon transmissions were successfully acquired on the first orbit by both the Pacific Missile Range Command and Data Acquisition Station at San Nicolas Island, California, and the Wallops Island, Virginia, Command and Data Acquisition Station. Both stations successfully commanded the satellite and received a total of 78 pictures taken by both cameras. Although the satellite's nadir angle during the first orbit was too high to permit the taking of meteorologically useful cloud-cover pictures, these first interrogations demonstrated that the satellite's subsystems were functioning normally and that the video quality from both cameras was excellent.

Engineering check-out of the satellite's subsystems was performed on orbit 003, when an interrogation was made by the AED back-up station at Princeton, New Jersey. Fifty-two frames of excellent video quality were received during this orbit. On subsequent orbits, the satellite's instrumentation was thoroughly tested, preliminary to full utilization. Pictures received during these early orbits showed cloud vortices in the Hudson Bay region, coastal and off-shore ice formations on the eastern coastline of Labrador, and many identifiable land masses including Spain, Gibraltar, North Africa, North and South Carolina, Mexico, and the Columbia River. All subsystems functioned reliably and provided excellent pictures and data to the ground stations. Analyses of the pictures showed that both cameras were returning pictures of very good video quality with excellent detail in the land masses and cloud structures. The pictures taken on orbit 004, presented in Figure I-1, are indicative of the quality of the pictures taken by both cameras in both modes of operation. The two pictures, made from almost identical points in the orbit, show two views of the same vortex. The definition of cloud detail is indicated in the picture taken over northwestern Africa by camera No. 1 on this same orbit (Figure I-2). The cellular cloud structure is clearly resolved in this remotely taken picture.

During the remaining days in June 1962, weather systems were observed in many areas of the world. Routine nephanalyses were prepared on a daily basis and special storm bulletins were sent to Nigeria, Iceland, Great Britain, and Ireland, regarding the locations of large circulation centers. A possible tropical storm was detected in the region of the West Indies and special advisories were sent to the Miami and New Orleans Weather Bureaus.

On July 8, 1962, Typhoon Joan was observed; the Joint Typhoon Warning Center at Guam and Air Force detachments in Hawaii and Japan were advised of the cloud patterns and the banding surrounding the typhoon. In addition to the regular teletype message, direct telephone communication was made with the Guam center.



a. Camera 1, Remote

b. Camera 2, Direct

Figure I-1. Storm Vortex Observed on Orbit 004 by Both Cameras

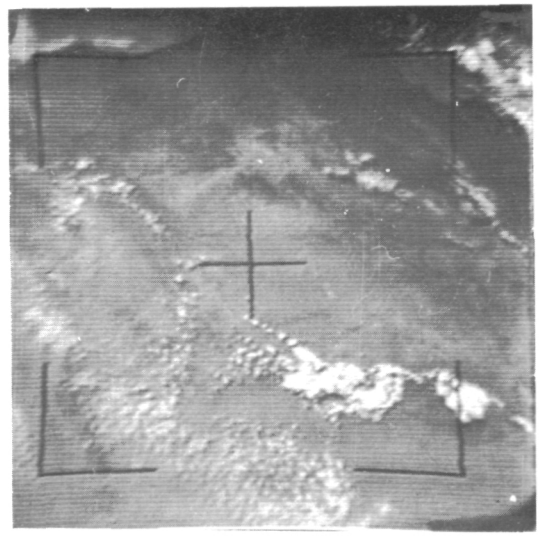


Figure I-2. Cellular Clouds over North Africa, Orbit 004, Camera 1, Remote

Observations of typhoons, tropical storms, and tropical depressions were made throughout July and August. Among these were Typhoon Ruth (Figure I-3), Typhoon Sarah (Figure I-4), Tropical Storm (later Typhoon) Thelma (Figure I-5), and Tropical Depression Ava (Figure I-6).

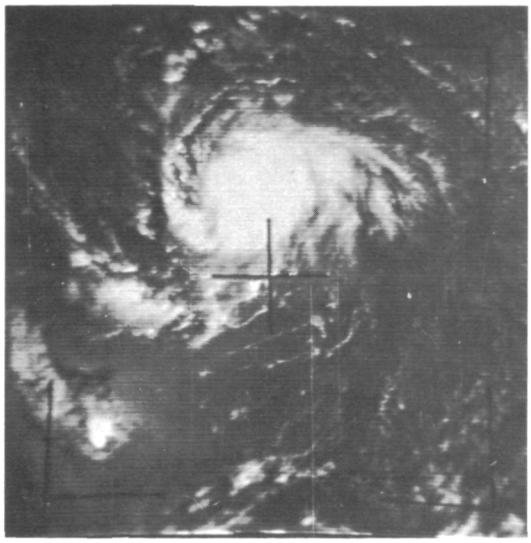


Figure I-3. Typhoon Ruth, Orbit 813, Camera 1, Remote

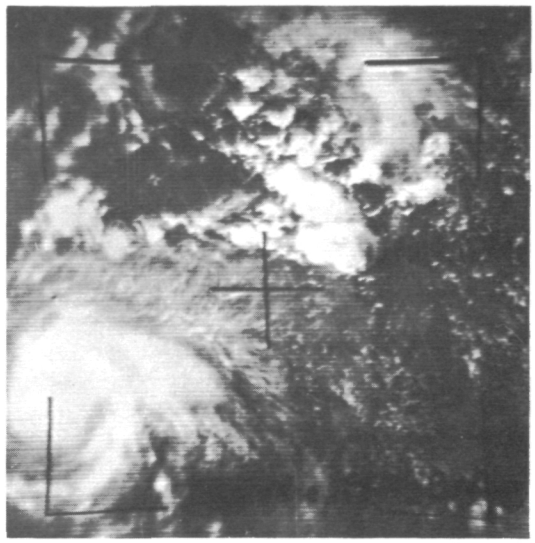


Figure I-4. Typhoon Sarah, Orbit 827, Camera 1, Remote

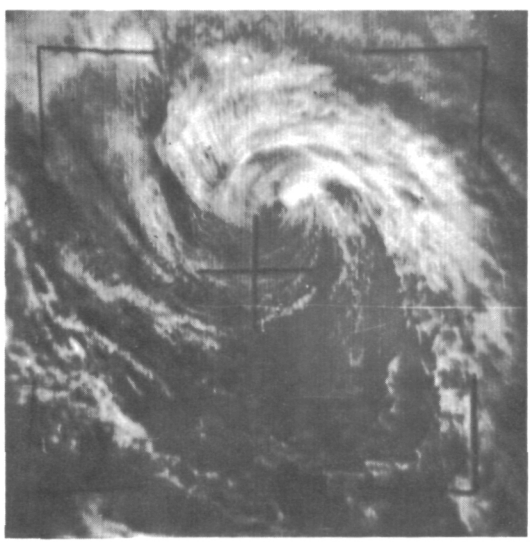


Figure I-5. Tropical Storm Thelma, Orbit 908, Camera 1, Remote

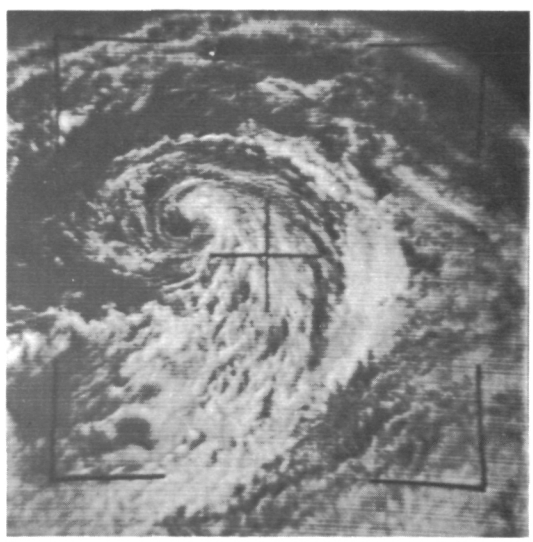


Figure I-6. Tropical Depression Ava, Orbit 936, Camera 1, Direct

In September, October, and November, Hurricanes Alma, Becky, Celia, and Daisy, and Typhoons Amy, Jean, Karen, and Wanda were observed. TIROS V was credited with the detection of Hurricane Becky in a remote region of the Atlantic before it had been detected by land-based weather-reconnaissance equipment. Pictures of several of these storms are shown in Figures I-7 through I-9. The progress of Typhoon Karen was followed from the South China Sea, along a path east of Guam and the Phillipine Islands and into a region southeast of Japan. Also during this period, polar ice packs were observed off the coast of Antarctica.

Figure I-7. Typhoon Amy, Orbit 1110, Camera 1, Remote

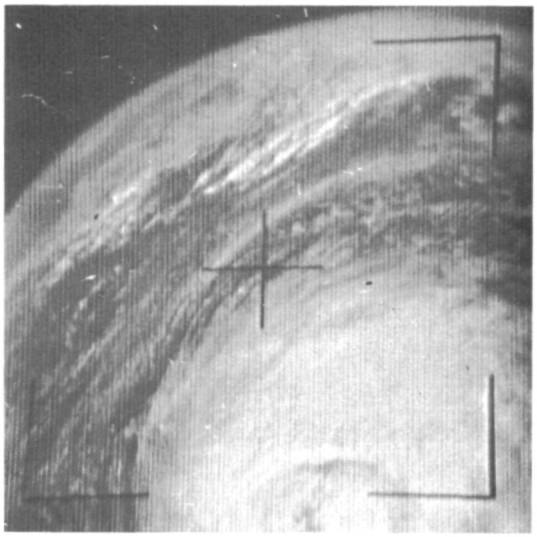
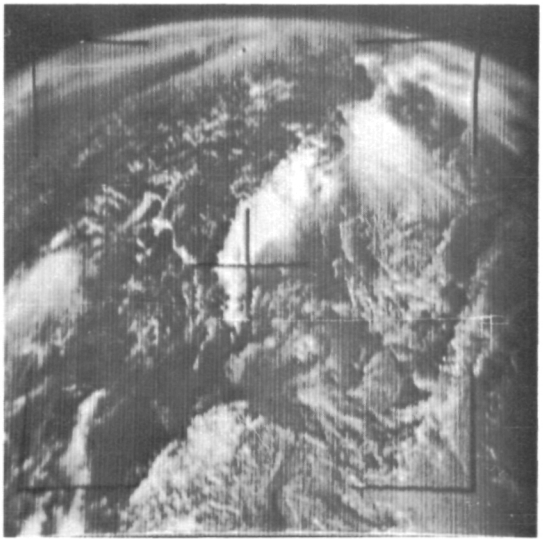
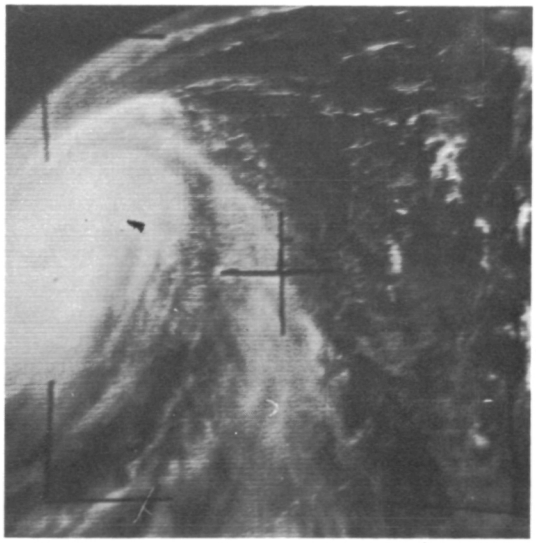


Figure I-8. Typhoon Daisy, Orbit 1549, Camera 1, Remote



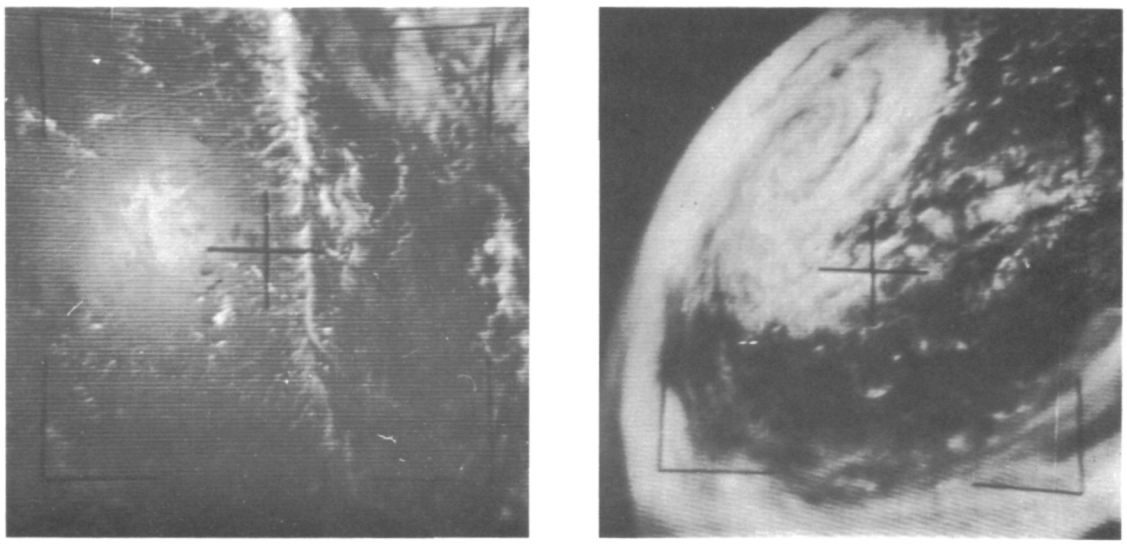
a. Orbit 2059, Camera 1, Remote



b. Orbit 2115, Camera 1, Remote

Figure I-9. Typhoon Karen, Forming over South China Sea (left) and, Later, East of Phillipine Islands (right)

During September and early October 1962, TIROS V was programmed in support of the Project Mercury launching of the MA-7 manned satellite. Over 1200 TV pictures returned by TIROS V were used in the preparation of 50 nephanalyses for Project Mercury meteorologists. A picture taken over the Indian Ocean east of the Malagasay Republic (Madagascar) in support of Project Mercury is presented in Figure I-10 (a). The picture in Figure I-10 (b) shows a large vortex over the primary recovery area.



a. *Solar Reflection from Indian Ocean, Orbit 1474, Camera 1, Remote*

b. *Vortex in Vicinity of Project Mercury MA-7 Program Primary Recovery Area, Orbit 1483, Camera 1, Remote*

Figure I-10. Pictures Taken in Support of Project Mercury

TIROS V continued to return pictures of good to excellent quality during the months of December 1962, and January through April 1963. Some of these pictures are shown in Figures I-11 through I-13. In March 1963, ice shelves were observed south of Australia, in the Scotia Sea, and near Wilkesland in the Antarctic. In late April, ice formations in the St. Lawrence River were observed and Typhoon Olive in the Pacific Ocean near the Marianas Islands was kept under surveillance for several days.

On May 5, 1963, after 320 days of operation in orbit, normal picture-taking ceased because of a malfunction in the electronics associated with camera system No. 1. However, by using special programming techniques, AED evaluation engineers were able to receive 12 pictures during orbit 4719 on May 15, 1963, 330 days after launch. One final picture was received on orbit 4731. In spite of the presence of some noise, which was probably associated with the malfunction, the high quality that was characteristic of the TIROS V pictures was evident right up to this final frame. The frame is shown in Figure I-13 (d).

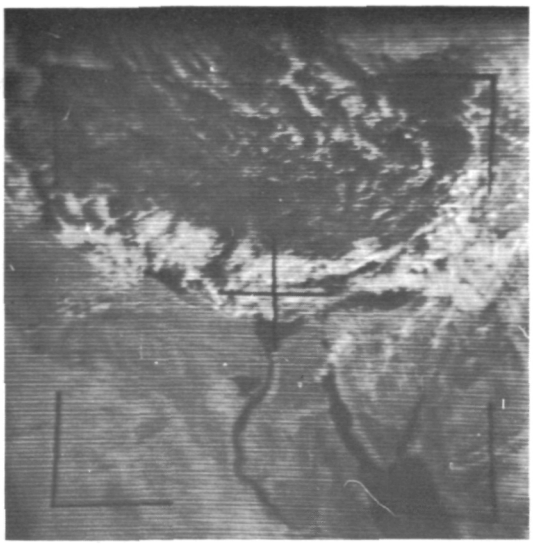
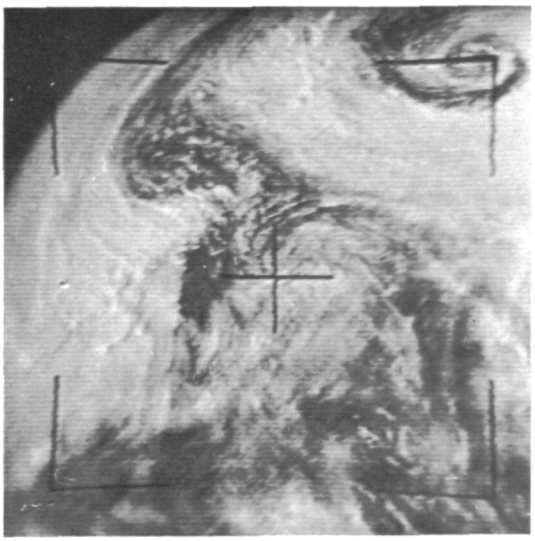
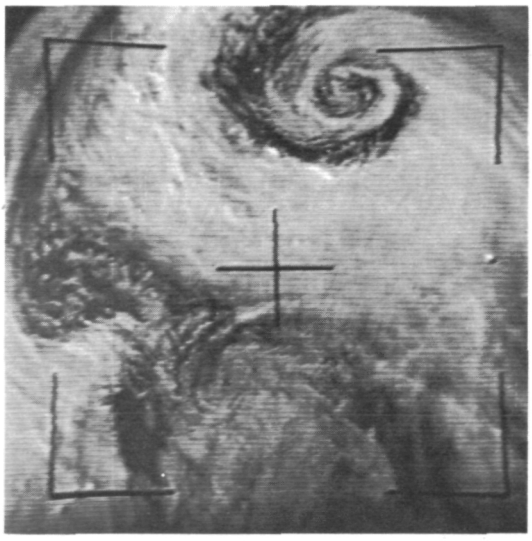


Figure I-11. Eastern Mediterranean Region, Orbit 2437, Camera 1, Remote

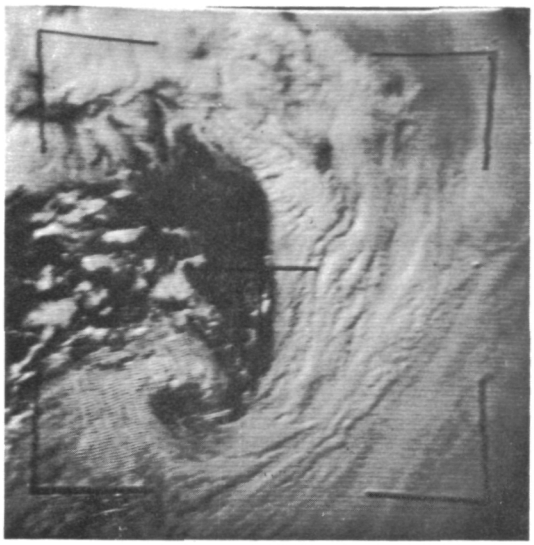


a. Orbit 3473, Camera 1, Remote

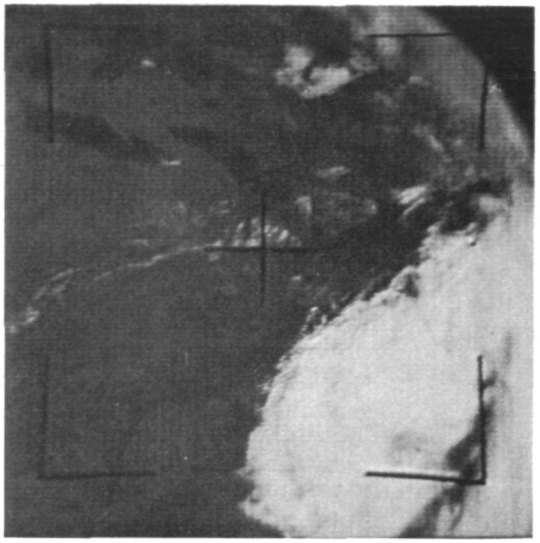


b. Orbit 3473, Camera 1, Remote

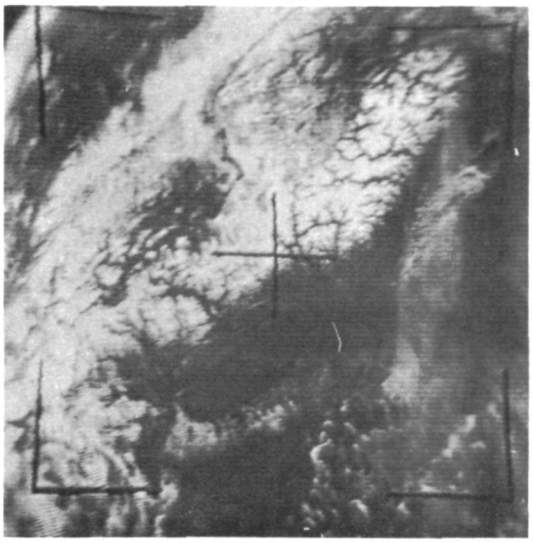
Figure I-12. Two Views of Strong Vortex Near Greenland Coast



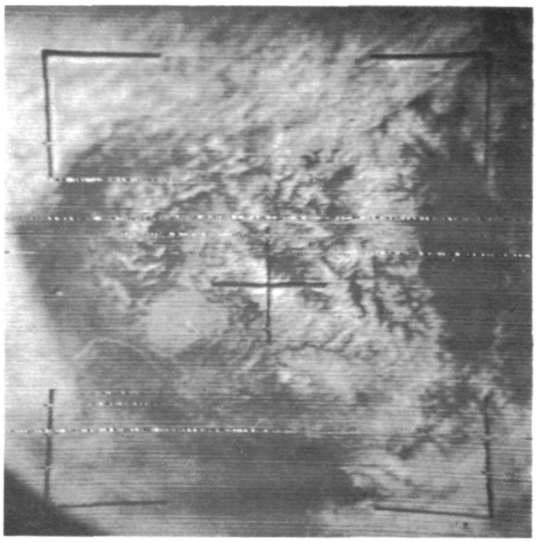
a. Orbit 4006, Camera 1, Remote (279th Day in Orbit)



b. Orbit 4545, Camera 1, Direct (316th Day in Orbit)



c. Orbit 4577, Camera 1, Direct (319th Day in Orbit)



d. Final Frame Received from TIROS V; Orbit 4731, Camera 1, Remote

Figure I-13. Late-Orbit Photographs Taken in Both Modes of Camera Operation

II. SYSTEM DESIGN

The TIROS V Meteorological Satellite System was similar in design to the TIROS IV system except for modifications made to improve the performance or capability of several of the subsystems. These modifications included improvements in the circuitry of the TV cameras; a change in the configuration of the support arms for the omni-directional radiometer sensors, to reduce their effect on the transmitting radiation pattern; a change in the orientation of the horizon scanner, to increase its effectiveness at all satellite attitudes; and the use of a more efficient solar cell array. These modifications are described in detail in the TIROS V final engineering report.

The TIROS V spacecraft was approximately 42 inches in diameter, 22.5 inches high, and weighed 286.5 pounds. The more than 9100 solar cells used to supply the satellite's power requirements (half of which were the new "gridded" cells) were mounted over most of the top and side surfaces of the spacecraft. The command receiving dipole antenna was attached to the satellite's top surface, and a four-element transmitting antenna was attached to the bottom surface.

The satellite contained a wide-angle and a medium-angle TV-camera system. Each camera system consisted of a TV camera, camera controls, a video tape recorder, and a TV transmitter. The lens system for the wide-angle camera provided a 104-degree field-of-view, on the diagonal, corresponding to a surface-area coverage of approximately 700 miles square. The lens system for the medium-angle camera provided a 76-degree field-of-view, on the diagonal, corresponding to a surface-area coverage of approximately 500 miles square. The output of each camera system could be transmitted directly to an interrogating ground station or recorded on magnetic tape for later transmission to the ground. The storage capability permitted pictures to be taken of remote geographic areas, while the satellite was beyond communication range of the ground stations. Both modes of operation, direct and remote, were controlled by commands transmitted from the Command and Data Acquisition ground stations. The satellite responded immediately to commands for direct operation, taking and transmitting pictures over the area of the interrogating ground station; remote operation was controlled by clocks, one in each system, which were programmed by ground-station commands to delay the initiation of picture taking for up to five hours, and then to operate the cameras in a specific sequence.

The satellite contained two beacon transmitters, one operating at 136.23 Mc and the other operating at 136.92 Mc. Thirty-three of the satellite's most significant operating parameters and six calibration voltages were telemetered to the ground station by modulation of the beacon carriers at the start of each satellite-to-ground contact. Attitude-indicator data, which provided a means for determining the

attitude of the satellite's spin axis, was also sent to the ground complex by means of the beacon transmitters.

A set of nine solar-cell sensors, equally spaced about the periphery of the satellite, provided sun-pulse signals from which the angle (in the plane of the satellite's baseplate) between the TV-camera radial and sun-direction vector for each TV picture could be determined. This information, which was combined with the video subcarrier and transmitted by the TV transmitters, was used along with the spin-rate data to establish the north direction on each photograph.

The NASA infrared subsystem consisted basically of a five-channel scanning radiometer, a non-scanning radiometer, a magnetic tape recorder, a transmitter, and a pair of omni-directional radiometers. This equipment was of essentially the same design as the infrared equipment installed on the TIROS IV satellite.

Each of the five channels of the scanning radiometer was designed to measure infrared radiation in a different band. The individual channel identifications, the band assignments, and the type of data associated with the wave bands are listed in Table II-1.

TABLE II-1. SCANNING RADIOMETER CHANNEL ASSIGNMENTS

IR Channel	Band	Data
1	5.9-7.0 microns	Radiation from earth's troposphere
2	0.6-0.8 microns	Visible spectrum (for reference)
3	0.2-5.0 microns	Earth's albedo
4	7.5-30 microns	Earth's total emission
5	8.0-12 microns	Surface or cloud emission

The non-scanning radiometer had a wider field-of-view than the scanning radiometer. It consisted of two cone-type IR sensors (one black and one white) with their sensitive axes parallel to the satellite's spin axis. The sensors "looked" through openings in the satellite's baseplate. The black cone was sensitive to radiation in the 0.2- to 50-micron region in order to measure the earth's total reflected and radiated thermal energy. The white cone was sensitive only to the earth's thermal radiation (5 to 30 microns).

The omni-directional radiometer consisted of two pairs of black and white sensors mounted 180 degrees apart on extension arms which projected outward from the satellite in the plane of the baseplate.

The black sensor was designed to measure (1) radiation from the sun, (2) reflected short-wavelength radiation from the earth, and (3) long-wavelength radiation in the infrared band from the earth. The white sensor was designed to measure the long-wavelength reradiation from the earth. The combined measurements from the black

and white sensors encompassed the total spectrum of the earth's thermal-radiation characteristics. This device was similar to one which was developed for Explorer VII and used on the TIROS IV satellite.

Four devices for controlling the satellite's dynamics were carried on the TIROS V satellite. These were, a precession damper, a de-spin mechanism, five pairs of spin-up rockets, and a magnetic attitude-control device. These devices were of identical design to their counterparts used on the TIROS IV satellite.

The precession dampers were uncaged after the separation of the satellite from the third-stage rocket, to dampen any "wobble" caused by precession or nutation. The satellite's operational spin rate is dictated by a maximum, above which the TV pictures would exhibit "smearing," and a minimum required for gyroscopic stabilization of the spin axis. Satellite spin-down from the relatively high orbit-injection spin rate required for stabilization of the third-stage rocket and satellite combination to an operational spin rate was achieved by activation of the de-spin mechanism. This mechanism automatically deployed a pair of spin-reducing weights four to seven minutes after the satellite had separated from the third-stage rocket.

Five pairs of spin-up rockets were installed about the periphery of the baseplate. The firing of pairs of these rockets was controlled by the ground station so that the satellite spin rate could be increased after it had been reduced by drag resulting from the earth's magnetic field.

The attitude-control device consisted simply of a 250-turn coil of wire, wrapped about the periphery of the satellite, and a 12-position switch that controlled the amount and direction of current in the coil. Using this device, the satellite's magnetic-dipole strength was controllable by ground command. The spin-axis could be moved a maximum of 15 degrees per day by this control over the interaction between the satellite's magnetic field and the magnetic field of the earth.

The TIROS V ground complex consisted of two primary Command and Data Acquisition (CDA) stations, a back-up CDA station, and selected stations of the U.S. Minitrack Network. One of the Minitrack stations, located at Santiago, Chile, was provided with a limited command (clock-start) capability to extend the remote picture-taking capability to orbits on which the satellite was out of contact with either of the CDA stations. The locations and the operations of the various stations in contact with the satellite were the same as for TIROS IV.

The primary CDA stations were used for commanding or programming the satellite's picture-taking sequences, for receiving and processing sun-angle and telemetery data, and for receiving and processing the TV-picture data received from the satellite.

The back-up CDA station, located at the Astro-Electronics Division of RCA, had the same capabilities as the primary CDA stations. This station was used as necessary throughout the operational period of TIROS V to perform engineering checks of spacecraft operation and, on occasions, to assume CDA responsibility during periods of inoperation of the Wallops Island station. The stations of the NASA Minitrack Network provided satellite-tracking data.

The areas of the earth to be photographed by the satellite were determined by the U.S. Weather Bureau and specified by requests to NASA. These requests were then examined at the TIROS Technical Control Center (TTC), located at the Goddard Space Flight Center, and became the basis for the operating programs. Detailed program instructions were teletyped from TTC to the cognizant CDA station, where they were used in programming the station's command and control equipment. The program instructions specified the areas to be photographed, the camera system or systems to be used, the order in which the camera systems were to be used, and the number of set-pulses to be sent to the satellite's clocks. When the satellite came within communication range of the CDA station, the pre-set program was read out and transmitted to the satellite at high speed. High-speed transmission of the pre-set program commands allowed time for both the playback of data that had been stored by the satellite and the taking of direct pictures, during the relatively short period of each contact.

III. EVALUATION SUMMARY

TIROS V was the fifth successful satellite of the TIROS program in as many attempts. Launched on June 19, 1962, TIROS V was used extensively in the detection and surveillance of autumnal hurricanes and typhoons. Its operational life extended well beyond this period, providing coverage of world weather patterns and ice formations until early May in 1963. Camera system No. 1 was continuously and fully operational for 320 days and partially operational for 10 days thereafter. The operational life of camera system No. 2 was 261 orbits (18 days), being cut short by a vidicon filament failure. The two camera systems produced a total of 58,226 TV pictures of good-to-excellent quality. Of these 49,236 (84.5 percent) were useful for meteorological analysis. This was by far the greatest quantity of pictures produced by a meteorological satellite up to that date, yielding the highest percentage of useable pictures and exhibiting the highest and most consistent video quality through the operational period.

The pictures from both cameras provided data for 1843 Weather Bureau nephanalyses and for 395 storm bulletins and advisories. The experimental transmission of TIROS pictures to weather stations over facsimile circuits was continued with good results.

The instrumentation control subsystem performed reliably and without malfunction. The satellite responded to all commands and the accuracy of clock setting was high. Performance was markedly improved by the reset capability of the TIROS V clocks. This capability permitted the clocks to be reset on command rather than by "oversetting," i.e., setting the clock to capacity so that it would alarm almost immediately. The performance of the telemetry and tracking subsystem was also very satisfactory. Beacon transmitter signal levels were high and did not decrease with time. The telemetry data was accurate with the exception of an isolated instance of telemetered component temperatures (telemetry points 36 through 39 on the low frequency beacon and 30 and 31 on the high frequency beacon) which fell below the range of the sensors on several readouts beginning on February 21, 1963. This was found to result from an unusual program sequence which was used to provide a 235-Mc tracking signal for the medium-gain antennas. This sequence caused the voltage available to the component temperature telemetry sensors to decrease. When the use of this program sequence was stopped, these telemetry readings returned to normal.

Both the attitude-indicator subsystem and the north-indicator subsystem performed well. Beginning on orbit 22, no north indicator playback data was received from camera system No. 1. However, a highly successful emergency procedure was quickly devised which made possible the use of system No. 2 north-indicator data

for the orientation of system No. 1 pictures. The loss of the system No. 1 data resulted from a malfunction in the tape recorder electronics associated with the recording or playback of sun-angle data. No evidence was present of any abnormality in the north-indicator subsystem itself. A minor problem in the attitude-indicator subsystem was encountered when a "sun-pulse," caused by sunlight falling on the horizon scanner IR sensor, appeared on the attitude-indicator data. Although potentially a problem at certain satellite attitudes, this pulse was not of sufficient magnitude in the TIROS V data to prevent easy identification of the genuine horizon pulses.

The precession damping mechanism, the "yo-yo" de-spin mechanism, the spin-up rockets, and the magnetic-attitude control performed normally. The performance of the new spin-up rockets used on TIROS V was greatly improved over the performance of rockets on TIROS III and IV. Fired on orbits widely spaced over the operational life of the satellite, the rocket pairs consistently produced spin-rate increases close to the nominal design value of 3 rpm. A new computer program was written for the satellite's attitude predictions and resulted in increased prediction accuracy. The long life of the satellite in orbit provided valuable data on the long-term effects of magnetic biasing. These data are the basis for suggestions included in this report for further improvement in the analysis of the observed data and in the predictions.

The satellite antennas performed normally throughout the operational period of the satellite. The radiation patterns of the satellite antennas were excellent, indicating that modification of the omni-directional experiment sensor-support arms had eliminated the problem of simultaneous fading experienced on TIROS III and IV. Although difficulties were occasionally encountered with the autotrack mechanism and electronics of the ground station antennas, the general performance of these antennas was also good.

Despite the long life of the satellite and its exposure to the artificial radiation belt created by the Johnston Island high-altitude nuclear explosion on July 9, 1962, the electrical power subsystem supplied normal voltages to the satellite subsystems on all but a few occasions. The reduced voltage on these occasions was caused mainly by intentionally programming to expend excess power and thus prevent overcharging the storage batteries. When this practice was stopped, the bus voltage quickly returned to normal.

The thermal response of the satellite was in good agreement with the expected values. As anticipated, the telemetered temperatures were 2 to 8 degrees C lower than on the previous satellites. The lower temperatures were the result of changes in thermal characteristics and of the inactive IR subsystem. The thermal characteristics were altered by the use of an additional piece of thermal insulation on the satellite hat and by the use of gridded solar cells in the solar cell array. The "gridded" solar cells have a lower net absorptivity-to-emissivity ratio (less heat was absorbed and more was emitted) than the ungridded cells

used on the previous satellites and their use on TIROS V thus resulted in lower temperatures of the satellite components. The temperatures remained within design limits throughout satellite operation in orbit.

The performance of ground-station equipment and operating personnel was very satisfactory. The more uniform processing procedures and equipment in use at the ground stations resulted in a general improvement in photographic quality and in processing efficiency. The generally good performance of equipment and personnel is evidenced by the high percentage of usable TIROS V pictures.

IV. TV PICTURE SUBSYSTEM

A. FUNCTION

The TV-picture subsystem for TIROS V consisted of the satellite equipment for taking, storing, and transmitting television meteorological pictures and the ground equipment necessary for receiving, displaying, and recording the pictures. The satellite equipment comprised two separate and independent TV-camera chains, identical except for the camera lenses. Camera system No. 1 was provided with an Elgeet wide-angle lens, with a 104-degree field-of-view, corresponding to a ground-area coverage of approximately 700 miles square from a nominal altitude of 400 miles. Camera system No. 2 was provided with a Tegea-Kinoptic medium-angle lens, with a 76-degree field-of-view, or a ground area coverage of approximately 500 miles square.

Each camera chain consisted of the TV camera, a camera-electronics package, a magnetic tape recorder, and a radio transmitter. Each TV chain was capable of independent picture-taking in either of two modes. The direct mode of operation was used when pictures were to be taken while the satellite was within communications range of one of the CDA ground stations. In this mode, pictures were taken and, without being recorded, transmitted directly to the interrogating ground station. When pictures were to be taken over an area of the earth remote from either of the CDA ground stations, the remote mode of camera operation was used. In this mode, the satellite was programmed to start taking pictures after a specific delay period, corresponding to the time required for the satellite to reach a position in its orbit over the area of interest. The pictures taken remotely were stored by the tape recorder until the satellite again came within range of a CDA ground station. Upon interrogation of the satellite by the ground station, the recorded pictures were played back from the tape and transmitted.

In both modes of picture-taking, the camera generated an analog video signal with a spectrum of approximately 62.5 kc. This analog signal produced linear deviation of an 85-kc subcarrier oscillator in the recorder-electronics unit. When direct pictures were being taken, the frequency-modulated video subcarrier was fed directly to the 235-Mc TV transmitter for FM transmission to the ground station. When remote pictures were being taken, the video subcarrier was recorded on magnetic tape. Upon receipt of the appropriate interrogation from a ground station, the video subcarrier was played back from the tape and fed to the TV transmitter.

Each satellite transmission of direct or remote pictures was accompanied by sun-angle data that originated in the nine sun sensors, spaced about the periphery of the satellite. A separate subcarrier of 10 kc, modulated on the 235-Mc TV carrier,

conveyed the sun-angle information. The sun sensors produced pulses of three characteristic widths as the satellite rotated and each sensor, in turn, scanned the sun. The pulse widths were assigned to the sensors in a manner such that any two consecutive pulses occurring during a picture frame were sufficient to reveal the orientation of the TV camera with respect to the sun.

The pulses produced by the sensors were converted to 10-kc bursts of the same durations as the original pulses. In the direct mode of picture-taking, these 10-kc bursts were combined with the video subcarrier before it was fed to the TV transmitter. During remote picture-taking, the 10-kc bursts were recorded on a separate channel of the tape recorder. When the tape recording was played back for transmission of recorded data to the ground station, the 10-kc bursts were reconstituted (to ensure a sun-pulse subcarrier frequency of exactly 10 kc) and then combined with the video subcarrier. The combined video subcarrier and sun-angle signal were applied to the TV transmitter. This data, in addition to satellite attitude data, was used to determine the orientation of each picture frame during interpretation on the ground.

The antennas and the coupling and matching network were identical in design to those used for the TIROS IV satellite.

The TV transmissions from the satellite were received at the CDA ground station by two receivers connected for polarization-diversity reception. Bandpass filters were used to separate the video subcarrier and the sun-angle subcarrier. The video subcarrier was demodulated and the video signal was applied to video electronics circuits for display on a kinescope and to a magnetic tape recorder for storage. A time-reference output from the video electronics was applied to an index computer which generated, in binary form, a frame number for display with each picture. The index computer also provided, from signals originating in the ground equipment, index data identifying the satellite camera or tape recorder associated with each frame, for display with the TV picture. Provision was made for photographing the kinescope display, including the index data, with a 35-millimeter camera. The sun-angle data, after being separated from the video signal, was fed to a sun-angle computer, which provided sun-angle data in binary form to be displayed and photographed along with the TV pictures and other index data.

The ground-station equipment was essentially the same as that which had been used for TIROS IV.

B. PERFORMANCE EVALUATION

1. Camera System No. 1

a. General

During its 320 days of operation, camera system No. 1 returned a total of 53,535 TV photographs, of which 45,998 (85.9 percent) were meteorologically useful. Of the total pictures taken 47,653 were remote pictures and 5,882 were direct pictures. The photographs reproduced in Section I of this report clearly show the generally excellent quality of the pictures. The fact that the overall quality of TIROS V pictures was better than that of previous meteorological satellites was especially noticeable during the late orbits. The late-orbit pictures remained focused both optically and electrically and exhibited good contrast. This indicates that the initial gain-level setting was optimum and that it did not change with temperature or time. The constantly good focus and contrast gave evidence of the improved performance and reliability of both the focus-current regulator, which had been redesigned for TIROS V, and the beam-current regulator, which had been added to TIROS V. Pictures taken throughout the operational period were examined for centering, size, aspect ratio, focus, and general picture quality. For this analysis, film negatives were selected at random from orbits covering the satellite's operational life. These negatives were then projected and examined in detail. The results of the analysis are given in Table IV-1. As shown in this table, the pictures taken by camera No. 1 were initially off center, to the left, by 6 percent. However, this centering error did not affect the usefulness of the pictures. The cause of the initial centering error was investigated. It was found that the shift had been first present following the final spin-balancing of the spacecraft/third-stage rocket combination at the launch site.

Two possible causes were investigated. One possible cause was a shift in the position of the camera; the second was a shift in the adjustment of the centering potentiometer. Attempts were made at AED to produce a shift in camera position by spinning the prototype spacecraft. The efforts did not produce any change in camera positioning, indicating that the cameras were mounted firmly enough to withstand the centrifugal force of spin-balance testing. Although no positive conclusion could be reached, the centering potentiometer was suspected as the source of the problem. The circuit has been redesigned to reduce the sensitivity of the potentiometer on future TIROS cameras.

During the early orbits, the pictures from camera No. 1 exhibited a tendency to return to correct horizontal centering. By orbit 638, the pictures were correctly centered and remained within 1.3 percent of center for the duration of satellite operation.

TABLE IV-1. TV PICTURE EVALUATION MEASUREMENTS, CAMERA SYSTEM NO. 1

Orbit	Centering Error		Error in Aspect Ratio (%)	Error in Picture Size (%)
	Horizontal (%)	Vertical (%)		
003	6	0	0	0
006	6	0	0	0
019	6	0	0	0
031	3	0	0	0
043	6	0	0	0
205	4	0	0	0
499	4	0	0	0
638	0	0	0	0
756	0	4	0	0
908	0	6	0	0
1150	0	5	0	0
1360	0	5	0	0
1506	0	6	0	0
1732	0	5	0	0
1975	0	2.0	1.6	1.3
2140	0.7	1.3	0.9	4.0
2394	1.3	1.4	2.5	1.7
2548	0	1.9	0.7	1.7
2749	0	3.3	0	2.4
3059	1.2	3.0	1.5	1
3249	0.7	2.0	1.6	3.7
3360	0	0.6	1.6	4.9
3573	0.3	1.9	2.4	2.2
3752	0	2.6	0	3.7
3954	1.2	2.5	0.7	1.7
4347	0.6	3.1	3.0	0.7
4550	0.6	3.1	1.5	0.6
4731	1.3	2.0	4.0	1.6

Initially, camera No. 1 pictures were centered vertically. On orbit 746, the pictures were vertically displaced above center by 4 percent. After remaining above center by 5 to 6 percent until orbit 1975, the pictures shifted slightly below center. For the remainder of the operational period, the camera No. 1 pictures were below center by 0.6 to 3.1 percent. On 90 percent of the frames examined, picture centering was within the specification figure of ±5 percent. On the remaining

frames, the centering deviation was a maximum of 1 percent in excess of the specified figure. It should be noted that centering errors never affected the usefullness of the pictures.

The aspect ratio of pictures from camera No. 1 remained at the preset value of 1.0 until orbit 1975, when it decreased to 0.984 (an error of 1.6 percent). On orbits 2749 and 3752, the aspect ratio returned to 1.0. On orbits 3360 and 3954, the ratio was 1.016 and 1.007, respectively (errors of 1.6 percent and 0.7 percent). In all other orbits, the aspect ratio was less than 1.0, but at the most by only 4 percent.

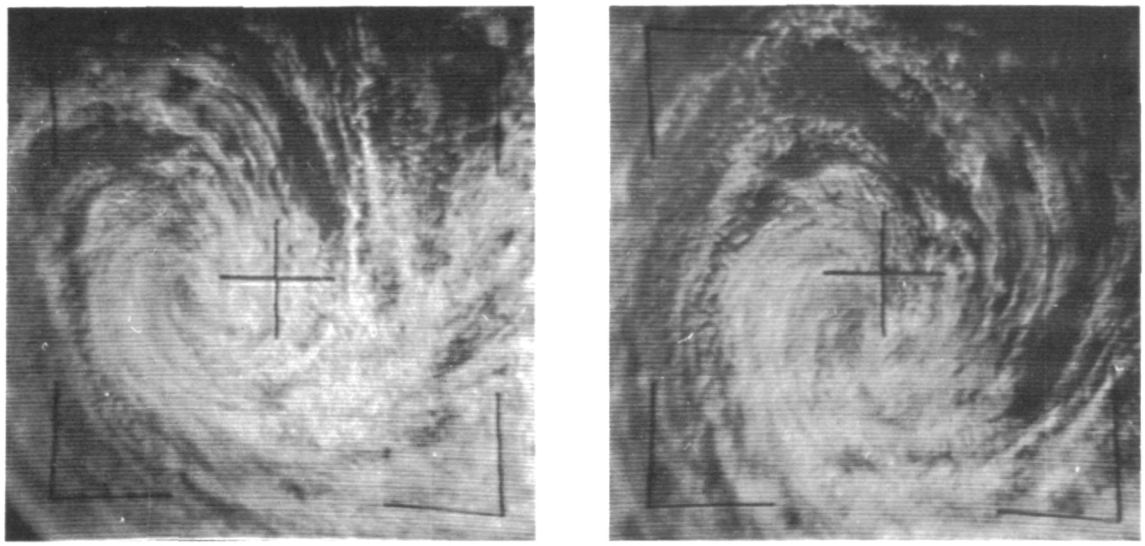
Resolution was determined through comparisons of the TIROS V photographs with detailed photographs from cameras of known resolution. The resolution of the TIROS V photographs was determined to be between 350 and 375 lines.

The time required for camera warmup was also evaluated. Pictures taken by previous TIROS satellites had shown, in varying degrees, the effects of an increase in vidicon warmup time as the vidicons aged. However, throughout the extremely long operational life of TIROS V, no problems were encountered as the result of vidicon warmup time. This was another indication of the improvement achieved by beam-current regulation.

b. Shutter Operation

Several problems related to operation of the camera shutter and shutter drive circuit occurred in camera system No. 1. These problems included frames in which multiple images appeared, frames in which horizontal bars were present at a 5-cps rate, and frames in which no video information appeared.

The horizontal bars first appeared on orbit 019 and continued thereafter on every other frame. In Figure IV-1 these bars can be seen superimposed over the normal video on frame 20. On frame 19, the bars do not appear. Despite the bars, the video information is clearly discernible. These bars are believed to be a form of microphonics which occurred when the shutter struck the part of the housing that limits its travel. The shutter reverses its direction of travel on alternate frames and was probably striking the mechanical limit harder in one direction of travel than in the other. This would account for the bars appearing on alternate frames.



a. *Orbit 1658, Camera 1, Remote, Frame 19; No Evidence of Horizontal Bars is Present*

b. *Orbit 1658, Camera 1, Remote, Frame 20; Showing Bar Pattern*

Figure IV-1. Camera 1 Pictures Showing Presence of Horizontal Bars on Alternate Frames

The occurrence of multiple-image frames was very rare and apparently random in nature. An example of this problem can be seen in Figure IV-2, which shows a playback frame received during orbit 2115. This is frame "2" in order of playback, or "31" in the order of recording. The picture contains three images, as can be seen from the presence of three distinct horizons. Upon analysis, it was possible to determine that the primary, or most prominent, image was the one taken 30 seconds after the preceding frame. This is normal timing for remote recording. The other images on frame "2" are believed to have been taken 1.0 and 1.7 seconds before the most prominent image. Since the exposure time is measured with respect to satellite rotation, the secondary images could have been taken during previous rotations. However, the strength of the images suggests that this is not the case. Images from previous rotations would have faded more than was the case. On frame "4," the secondary image appeared approximately 1.8 seconds before the primary image. The shutter operations which produced the extra images do not appear to have been caused by incorrectly timed shutter pulses, since tape recorder operation was not initiated at the time of the extra shutter operations. Thus, it is believed that the problem was caused by erratic triggering of the shutter circuit.

The reception of blank frames on some orbits is also attributed to erratic triggering of the shutter. Although the cause of this problem is not definitely known, it is believed that spurious shutter pulses caused the direction-control multivibrator to change state at times when the shutter-solenoid enabling voltage (minus 26 volts, unregulated) was not present. Thus, at the next genuine shutter pulse, the solenoid would attempt to move the shutter in the same direction in which it had last travelled and the exposure would be lost.

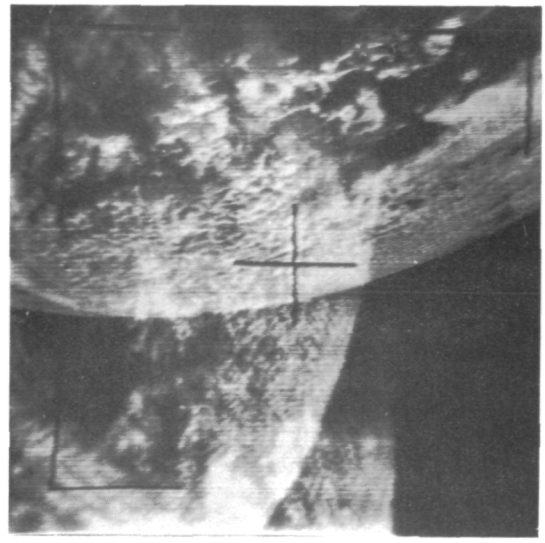


Figure IV-2. Orbit 2115, Camera 1, Remote, Showing Triple Exposure

On May 5, 1963, after 320 days of operation in orbit, camera system No. 1 returned only blank frames in response to interrogations from the ground stations. The condition persisted, and on May 14 (orbit 4719) AED performed an engineering analysis of the failure. The satellite was programmed by the AED ground station to test a theory that diode CR310, in series with the minus 24.5-volt power input to the shutter drive circuit, had failed. The TV-camera subsystem was programmed for alternate operation of the cameras. In this type of operation, power is applied to the camera No. 1 shutter-drive circuit through diode CR310 in the camera No. 2 circuit.

Twelve frames of video were received from camera system No. 1 during this test programming, strengthening the theory that diode CR310 in the camera No. 1 circuit had been the cause of the problem. On orbit 4731 the last picture was received from TIROS V by the PMR ground station. Subsequent attempts to read out the satellite were unsuccessful and it was concluded that diode CR310 in the camera No. 2 circuit had also failed. It therefore seems probable that initially a component failure in the camera No. 1 circuitry caused a high-power drain which, in turn, resulted in the failure of diode CR310. Then, when power was applied to the circuit through diode CR310 in the camera system No. 2 circuit, that diode also failed, after several successful operations.

2. Camera System No. 2

a. General

Camera system No. 2 returned 4691 TV pictures, 422 in the direct mode and 4269 in the remote mode. Of the total, 3238 pictures (69 percent) were useful to meteorologists. Figure I-1 (b) is typical of the good quality of these pictures from the first orbit until operation ceased on orbit 261. The pictures from this camera system were analyzed in the same manner as those of camera system No. 1. The results of the analysis are presented in Table IV-2.

TABLE IV-2. TV PICTURE EVALUATION MEASUREMENTS, CAMERA SYSTEM NO. 2

Orbit	Centering Error		Error In Aspect Ratio (%)	Error In Picture Size (%)
	Horizontal (%)	Vertical (%)		
004	6.5	0.4	5.4	3.7
019	8	0	1.2	0
031	7	0	3.0	0
043	7	0	1.4	0
090	4.4	3.0	1.4	0
115	3.8	1.0	0	3
146	3.8	0.3	4.6	1.8
175	2.8	2.9	1.4	1.0
205	5	0	3.0	0
245	1.7	2.5	0	0

From this table, it can be seen that the camera No. 2 pictures were initially off-center in the horizontal direction (by 8 percent on orbit 019) and tended to return to center. By orbit 245, the pictures were off-center by only 1.7 percent. Initially, the pictures were centered vertically. The maximum vertical-centering error was 3.0 percent (orbit 90). For the pictures analyzed, the error in aspect ratio varied between 0 and 4.6 percent, and the error in picture size varied between 0 and 3.0 percent. However, as noted previously, these shifts did not affect the picture useability.

Camera system No. 2 continued to provide pictures of good to excellent quality, until orbit 255, on July 7, 1962. At that time, the playback No. 2 sequence produced 32 blank frames. However, normal playback sequences were obtained on the next several orbits. The absence of pictures on orbit 255 was then attributed to improper programming on orbit 254. This supposition was strengthened by

the fact that command-transmitter power had been reduced during orbit 254 to avoid commanding the TIROS IV satellite.

During orbit 261, all frames of a direct sequence from camera No. 2 were blank. Thereafter, all frames from camera No. 2, both direct and playback, were blank. The blank frames were analyzed and the telemetry from camera system No. 2 was studied to determine the cause of the problem.

Examination of the telemetry data revealed that the satellite had been programmed on several occasions on July 9 for telemetry readout of system No. 2. On all occasions, the telemetry point for the vidicon heater and focus-coil current (position No. 22) yielded a zero indication. Normal telemetry data was returned for the horizontal and vertical synchronizing signals and for the vidicon high voltage. These telemetry indications are confirmed by the normal synchronizing signals and the constant dark level in the video signal for all frames returned by camera system No. 2.

All TV-camera functions appeared normal, with the exception of the focus current and the vidicon-filament current. Consequently, since the focus coil and the vidicon filament are connected in series, the fault would have to be associated with one of these two parts or with the focus-current regulator, through which these parts are connected to the minus 24.5-volt supply. Life tests of vidicon filaments and failure-mode tests of the focus-current regulator circuit were conducted in order to determine the most probable cause of this problem.

b. Vidicon and Focus-Current Regulator Tests

Two series of tests were conducted to obtain additional data concerning possible failure modes of the vidicon heater and of the focus-current regulator. One test series was a life test of six vidicons. Power was applied to the filaments in a cycle consisting of 5 minutes of power ON and 25 minutes of Power OFF, simulating the normal duty cycle of the TIROS cameras. A record was maintained of heater voltages. This record was continued for 2680 cycles, after which one vidicon filament failed. The terminal resistances of the heaters were plotted from these data and are shown in Figure IV-3.

The plot for vidicon No. 103 is comprised of scattered points, yielding no smooth curve. Yet it is clear that No. 103 and Nos. 104, 113, 129, and 168 all exhibited a similar aging characteristic. Vidicon No. 190, however, possessed a drastically different aging characteristic. All six heaters had an initial downward trend in terminal resistance. After 600 test cycles, the resistance of No. 190 began to rise, while that of the others continued to decrease. As the others began to level off (or climb slightly in the case of No. 103), No. 190 climbed exponentially until, during the last 80 operations, the rise was nearly vertical, leading to failure on cycle 2680.

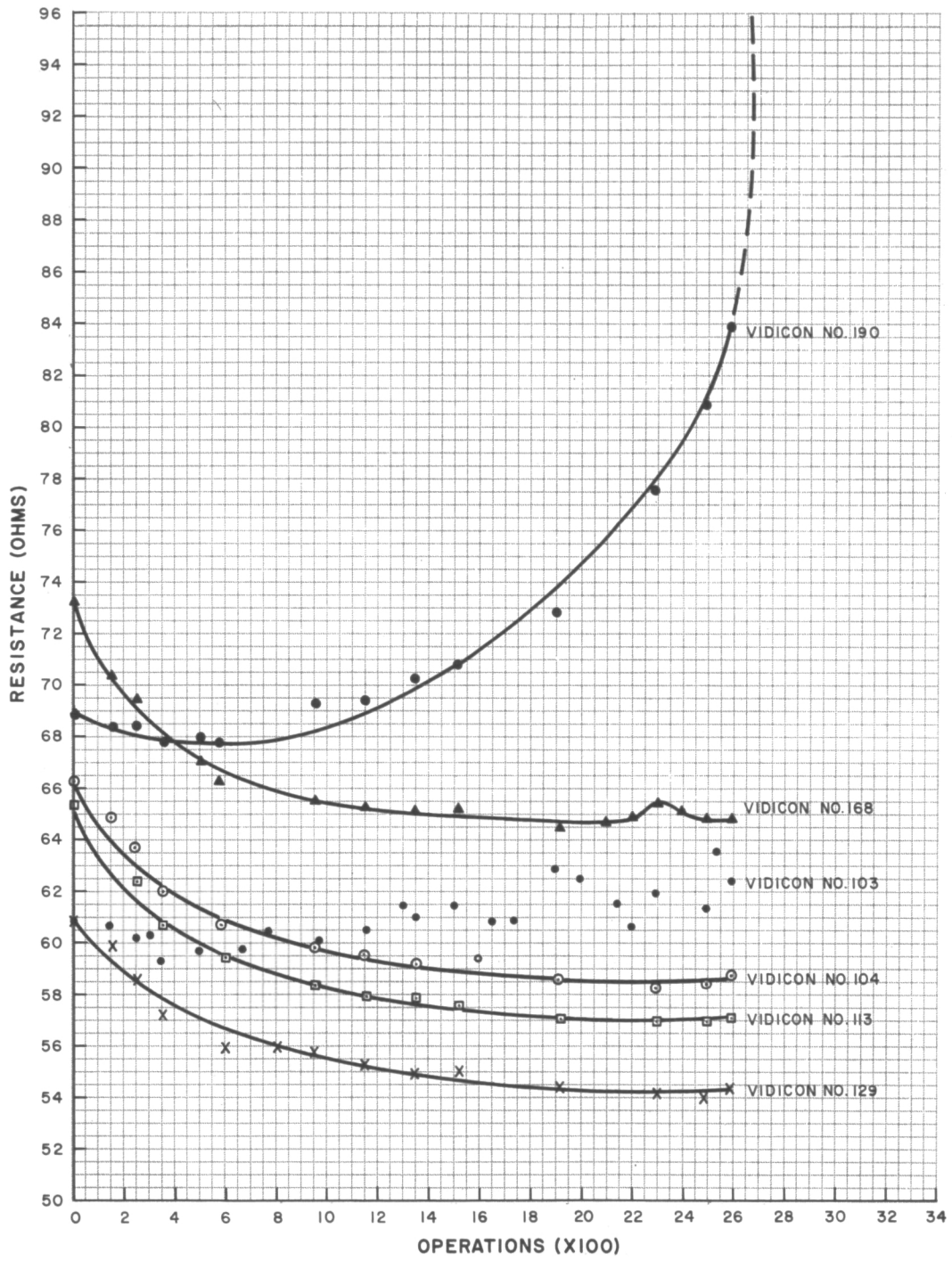


Figure IV-3. Vidicon Filament Test Data, Showing Filament Terminal Resistance versus Cycles of Operation

Life testing was continued and, after 15,400 cycles, a second vidicon filament failed. This failure occurred during the week ending November 10, 1963, after a total operating life of 1280 hours. During the last 10 days of December 1963, two more vidicons failed at the completion of 17,800 cycles and 1480 operating hours. Testing of the remaining two vidicons is continuing.

The data acquired so far in this test has revealed the presence of one vidicon in the sample of six which had a much shorter life potential than the normal. Much more testing would be required to establish a failure rate for the vidicons and to determine a characteristic failure mode. However, such testing could prove to be of great value in providing data from which potentially short-lived vidicons might be detected in early tests and removed from service.

Concurrently with the vidicon-heater life tests, a series of tests was made of the focus-current regulator to determine what failure modes of this circuit could cause total loss of heater and focus-coil current as observed in the TIROS V telemetry.

These tests indicated that any component failure in the reference voltage section of the regulator would result in a quiescent value of focus and heater current. The value, both computed and measured, was 74 milliamperes, corresponding to a telemetry indication of 1.6 volts at point No. 22. It was further established that an open circuit in the difference amplifier, Q314, would also produce a quiescent value of focus and heater current. A low beta (even as low as 1) of series regulator Q313 would not cause the second series transistor, Q315, to fail. A short circuit in Q313 would result in a quiescent value of focus and heater current.

In addition to these circuit-failure experiments, analyses were made of the electrical stresses applied to the components of the circuit. It was established that no components were overstressed, nor should aging of any part lead to overstressing and possible failure, with the possible exception of the 25-microfarad capacitor, C308. Tests were made in which the minus 24.5-volt power to the regulator circuit was suddenly switched on and off, to determine if the inductance of the focus coil would cause a large current transient to flow in C308. No large transient was produced by this switching.

Thus, it is concluded that the trouble did not lie in the focus-current regulator but most probably was a failure of the vidicon filament.

3. Tape Recorders

Both tape recorders performed normally during the operational periods of the respective camera systems, except for the remote recording and playback of sun-angle data in tape recorder No. 1. With this exception, the No. 1 tape recorder functioned well through 320 days of orbital operation, providing good frequency response, a minimum of wow and flutter, and no evidence of gross deterioration.

Tape recorder No. 2 operated well beyond the operational life of camera No. 2, and was used to provide sun-angle data for orientation of the pictures taken by camera system No. 1. It is believed that the condition evidenced by excessive wow in some of the pictures taken with the No. 2 camera eventually led to the failure of tape recorder No. 2.

Because of its long life, tape recorder No. 1 afforded an excellent opportunity for study of the long-term characteristics of the TIROS tape recorder in the space environment. A careful assessment was made of operating characteristics near the end of satellite operation; operating characteristics during the early and late orbits were compared. The following three criteria were chosen for these comparisons as being indicative of overall tape-recorder performance:

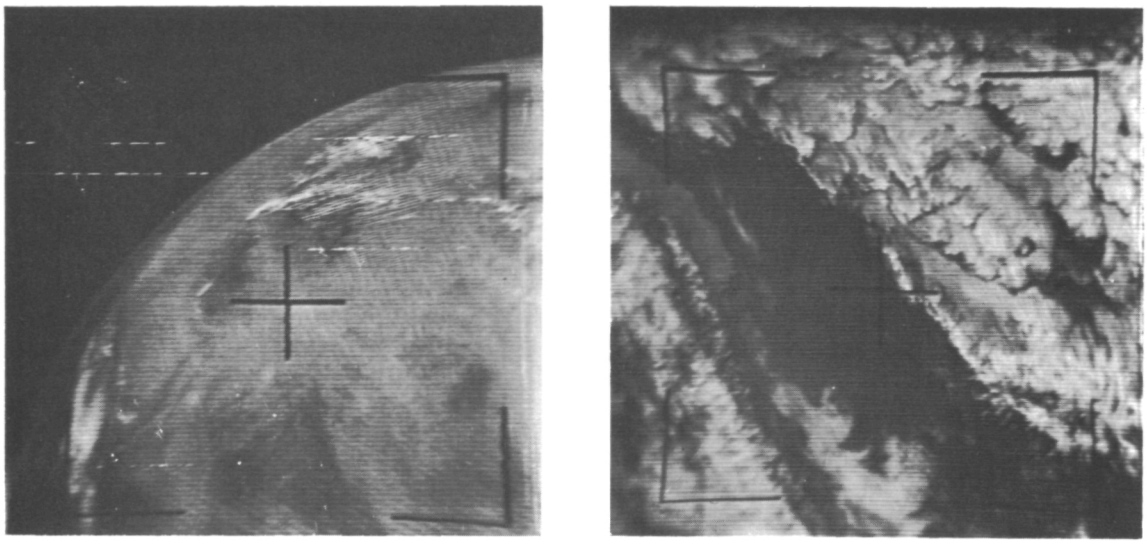
- Wow: the low-frequency variations in tape speed, which result in scalloping of the vertical edges of the TV pictures.
- Flutter: the high-frequency variations in tape speed, which can limit picture resolution.
- Signal Level: low signal levels result in correspondingly low signal-to-noise ratios.

The tape-speed variations are mainly a gauge of operation of the synchronous power converter, tape-drive motor, mylar drive belt, bearings, and other mechanical features of the tape transport. The signal levels are related to the condition of the magnetic tape and of the magnetic recording and playback heads.

Photographic negatives of many of the TV pictures taken during early and late orbits were examined in detail under magnification. In the late-orbit photographs, the reticle cross hairs and corner marks remained sharp, indicating that there was no degradation in the frequency response of the system as a whole. Sharp reproduction of the crosshairs requires a system frequency response of at least 21.2 kc.

The tolerances for rms wow and flutter, i.e., 0.3 percent rms, were met in all photographs examined. The amount of wow and flutter was determined by the maximum deviation of the reticle marks from their proper positions on the raster. A maximum deviation of 0.004 inch (approximately the width of a reticle mark) between the positions of the marks on any two lines of the raster is within the allowable tolerance for wow and flutter. The maximum deviation observed on the negatives was less than 0.004 inch, indicating that throughout the 320-day period there was no gross deterioration of the motor, bearings, drive train, drive belt, or of the synchronous power converter in tape recorder No. 1.

The negatives were examined for evidence of decreased signal levels. Slight momentary drop-outs were noticed on some of the frames from the playback of orbit 4304. As can be seen in Figure IV-4 (a), no loss of usefulness of the pictures resulted from these minute drop-outs. It is not possible to determine the cause of the drop-outs on orbit 4304. They could have been caused by momentary loss of contact between the magnetic head and tape or by momentary interruptions of the communications link. Typical of the high-quality remote pictures received during most orbits is the photograph shown in Figure IV-4 (b).



a. b.

Figure IV-4. Camera 1 Remote Pictures, Showing Tape Dropouts During Orbit 4304 (left) and Normal Remote Picture Typical of Camera 1 Remote Operation (right)

In general, the performance of tape recorder No. 1 was very good throughout the operational period. No significant deterioration of the unit was revealed by inspection of the negatives.

Starting with orbit 229, sun-angle data was missing from all of the remote-picture recordings of TV pictures from camera system No. 1. This data was, however, present in the direct-picture data. This problem could have been caused by a failure in any one of four of the circuits in the tape-recorder electronics. The four circuits involved in recording and playing back the sun-angle data are (1) the 10-kc oscillator, (2) the sun-angle (10-kc) recording amplifier, (3) the sun-angle (10-kc) playback amplifier and detector, and (4) the 10-kc gating circuit. The 10-kc oscillator operated normally during direct transmission of TV and sun-angle data. However, since it is supplied with power from separate sources during direct transmission and during playback, it could have been the cause of the difficulty. No definite determination can be made as to which of these circuits caused the loss of remote sun-angle data.

4. TV Transmitters

The TIROS V TV transmitters were identical to the TV transmitters used on TIROS IV. They provided a minimum power output of 2 watts at the operating frequency of 235 Mc.

Examination of the pass summaries and reports of signal strengths from the ground stations indicated that the transmitters operated normally and that there was no noticeable degradation of output power throughout the operational period. The high quality of the TV pictures indicated that the modulation circuits operated normally.

V. INSTRUMENTATION CONTROL SUBSYSTEM

A. FUNCTION

The instrumentation control subsystem consisted of the satellite and ground-station components required for remote control of satellite operations by the Command and Data Acquisition ground stations. The limited-command (clock-start) capability which was added at the NASA Minitrack Station in Santiago, Chile, for TIROS III operation, was also used for TIROS IV. This capability again allowed the satellite to take pictures during orbits when it was beyond the remote-picture clock-set capability of both CDA stations. The locations of the ground stations were such that during nearly all orbits of each day at least one station was within communication range of the satellite for a period of between 6 and 12 minutes.

The control subsystem permitted the satellite to be programmed for direct or remote picture-taking sequences, for playback of remotely acquired data, and for initiation of dynamics-control functions, i.e., magnetic attitude control and firing of spin-up rockets. In addition, the control subsystem provided a capability for turning off the satellite's beacon transmitters.

The satellite-borne components of the instrumentation control subsystem included two command receivers, two camera-control units, an auxiliary-control unit, two timing and sequencing (clock) units, a magnetic attitude-control circuit, and rocket-firing and beacon-kill control circuits. All of these components, except the command receiver and the clock-set circuit, were essentially the same as those which had been used on TIROS IV.

The all-electronic clocks, used on TIROS III and IV, were also used on TIROS V. However, the clock-set circuit was redesigned to permit the clocks to be set more accurately.

The ground-station components included a command transmitter, a control-tone generator, a command programmer, an antenna programmer, a master clock, a remote-picture time-set unit, a clock-set-pulse demodulator, and a relay power supply. These components were the same as those used for TIROS IV operation. The ground-station equipment controlled the programming of the tracking antennas, the initiation of commands to the satellite, the operation of the TV and data recorders, and the shutdown of the equipment at the end of a communication contact.

The satellite could be operated in any one of three modes; namely, direct, remote, and playback. Direct operation was programmed when it was desired to take cloud-cover photographs of the area surrounding the interrogating CDA station. Remote

operation permitted the satellite to be preset while in contact with a CDA station, so that it would take photographs over a geographically remote area and store the photographs on magnetic tape. Playback operation permitted playback of recorded cloud-cover photographs, including the related north-indicator data, and playback of the IR data recorded by the NASA IR experiment. When the satellite was neither in contact with a CDA station nor in a remote picture-taking sequence, it was in a standby condition.

The various modes of satellite operation, the program sequences that could be used in each mode, and the functions that could be performed in each mode are described in detail in the TIROS I final report.

B. PERFORMANCE EVALUATION

The satellite components of the instrumentation control subsystem operated reliably and without malfunction throughout the operational life of the satellite. The satellite responded reliably to transmitted commands and the accuracy of the clocks in initiating remote picture sequences was very satisfactory.

The automatic reset capability of the TIROS V clocks proved effective in eliminating the loss of remote-picture sequences that had occurred on previous satellites when it was necessary to clear the clocks of unknown numbers of pulses in order to achieve the reset condition. There were, however, instances in which remote sequences were lost, apparently because of accidental resetting of the clocks as the result of improper ground station command or interfering signals.

There are two possible ways in which an accidental reset could take place. The reset command shares the command channel for turning on the 500-cps converter for playback. If the command for 500-cps-converter-on becomes interrupted, a reset takes place. Such a reset would occur if the satellite received in succession the commands for playback, direct pictures, and then playback a second time. Aside from the possibility of incorrect programming, such a sequence of commands might occur during a normal playback as the result of heterodyning of the command carrier and an interfering RF signal. A reset could also occur during a direct picture sequence as the result of the command carrier heterodyning with an interfering RF signal to produce the playback command tone, or as the result of interference from an RF signal containing frequencies including the playback tone frequency.

The performance of the auxiliary control circuits was normal during the operational life of the satellite. Normal control of satellite spin-up, magnetic torquing, and telemetry readout was available throughout this period. A possible malfunction of the spin-up rocket control switch or circuitry occurred on June 11, 1963, after the operational life of the satellite had ended. This problem is discussed in detail in Section IX of this report.

VI. INFRARED HEAT-MAPPING SUBSYSTEM

A. FUNCTION

The infrared heat-mapping subsystem installed on the TIROS V Spacecraft was of nearly the same design as the subsystem used for TIROS IV. This equipment was supplied by NASA to measure heat radiation and reflection from earth and its environs in the infrared (IR) through ultraviolet portion of the electromagnetic spectrum. Provisions were included to allow the system (1) to continuously record the radiation data measured during an orbit on a continuous magnetic tape having a 100-minute storage capacity and (2) to play back and transmit the recorded data, at an accelerated rate, i.e., in a period of 3 minutes and 20 seconds, when commanded by an interrogate pulse from the TV picture subsystem.

Provisions were also made for recording and transmitting telemetric measurements of the temperature, pressure, and calibration of the IR package, and certain time-reference signals along with the radiation data. The equipment was designed to bypass data obtained during the playback periods around the tape recorder and to transmit the data directly to the ground stations at a normal (non-accelerated) rate, at the same time as the accelerated playback transmissions. Use of this technique ensured against loss of data measured during the playback period.

The operation of the subsystem is controlled by an interrogate pulse that is generated in the TV picture subsystem at the start of a direct camera sequence or at the beginning of playback of remote pictures. An IR control unit, built by AED, supplies three pulses of three distinct durations. These pulses provide time references based on the satellite's spin rate, the camera-shutter command, and the ground-initiated end-of-tape pulse.

The electrical operating power for the IR subsystem is derived from the satellite's power-supply subsystem. The satellite's transmitting antenna (including the coupling and matching network) is used for transmitting the measured IR data to the ground stations.

The NASA-furnished portion of the IR subsystem consisted of the following: (1) a scanning, five-channel radiometer (FCR) unit; (2) a non-scanning, two-element, wide-field radiometer (WFR) unit; (3) a pair of omni-directional radiometers; (4) a continuous-loop magnetic tape recorder; and (5) an IR transmitter. Other parts of the subsystem included a commutating switch, subcarrier oscillators, a DC-to-DC converter (power supply), and related electronics. The IR electronics, the IR transmitter, and the tape recorder were contained in a sealed, cylindrical canister.

The FCR unit consisted of a group of five thermistor-flake bolometers, each of which employed a suitable filter to provide sensitivity to wavelengths in a selected portion of the electromagnetic spectrum between 0.2 and 30 microns. The sensors are designed to alternately view the earth, through an opening in the baseplate, and space (for reference purposes), through an opening in the side wall of the satellite hat. The planes of the upward (space) and downward (earth) fields of view are both at a 45-degree angle to the baseplate horizontal reference. A system of prisms and five chopping wheels alternate the sensor's view between the earth and space.

The non-scanning, WFR unit was mounted on the satellite baseplate and was oriented to view the earth in a downward direction parallel with the spin axis. The unit consisted of one black and one white thermistor-flake bolometer; each bolometer was mounted at the apex of a separate cone and was identified as either the black cone or the white cone.

The omni-directional radiometer consisted of two pairs of black and white infrared sensors, mounted 180 degrees apart on extension arms projecting outward from, and in the plane of, the satellite baseplate. The black sensor was designed to measure the following parameters: (1) radiation from the sun, (2) reflected short-wavelength radiation from the earth, and (3) long-wavelength radiation, in the infrared band, from the earth. The white sensor was designed to measure the long-wavelength reradiation from the earth. The combined measurements from the black and white sensors encompass the earth's thermal radiation and reflection characteristics. This radiometer was similar to the one which had been developed for the Explorer VII satellite. It differed from its counterpart on the TIROS III and TIROS IV satellites in that the sensor-support arms were redesigned to eliminate a parasitic radiator effect which had been present on both of its predecessors in the TV and IR frequency bands.

The five-channel and wide-field radiometer outputs, as well as the telemetry and calibration signals from sensors within the IR package, were applied to six audio-frequency subcarrier oscillators of a self-contained FM/FM transmission system. Time reference signals from the IR-control unit were applied to a seventh, tuning-fork controlled, subcarrier oscillator as downward amplitude modulation. This oscillator also served as a frequency reference for calibration of the tape-recorder speed.

B. PERFORMANCE EVALUATION

During checkout testing of the spacecraft at Cape Canaveral, on the days just preceding the launching of TIROS V, the IR subsystem exhibited intermittent malfunctioning of the recorder and transmitter. These problems were analysed and corrective action was taken. However, after operating properly during checkout testing for three successive days, the subsystem again malfunctioned, this

time causing a very high power drain. After a series of tests on the launch stand, the malfunction was isolated to the DC-to-DC converter of the IR subsystem. At NASA's decision, the subsystem was permanently disconnected from satellite power prior to the launch, to prevent a possible recurrence of this problem in space from endangering the operation of the satellite's other subsystems. The components of the IR subsystem remained on board the spacecraft to preserve the moment of inertia, balance, and dipole moment of TIROS V.

VII. TELEMETRY AND TRACKING SUBSYSTEM

A. FUNCTION

The TIROS V telemetry and tracking subsystem was identical to its counterpart on TIROS IV.

The subsystem consisted of two beacon transmitters, one operating at a frequency of 136.23 Mc and the other operating at a frequency of 136.92 Mc; two telemetry circuits (for redundancy) which amplitude-modulated the beacon signals with signals representing the temperatures and voltages to be telemetered; and ground-based components that tracked the beacon signals and demodulated and recorded the telemetry data. The transmitting, receiving, and recording circuits in the telemetry subsystem were designed to provide an accuracy of ±5 percent of full scale on a Sanborn telemetry recorder.

The telemetry circuits consisted of temperature sensors, voltage and current sampling networks, a 40-position selector switch, and a 1300-cps (center frequency) voltage-controlled subcarrier oscillator (SCO) that was frequency-modulated by an analog input voltage from each of the 39 telemetry-data points. The upper and lower limits of the analog voltages were +2.5 and -2.5 volts d-c, respectively, corresponding to frequency shifts in the SCO of +100 and -100 cps. The voltage at each data point was momentarily applied to the SCO by means of the 40-position stepping switch. Upon receipt of a ground command, the switch stepped through its 40 positions, remaining at each of the 39 data-point positions for 0.8 second and stopping at the 40th, or "home", position. The voltage at each data point caused a momentary (0.8 second) shift in the SCO frequency.

The resultant, frequency-shifted, SCO output was used to modulate the associated beacon transmitter for transmission of the telemetry data to the interrogating ground station. The second beacon system provided redundant transmission of the telemetry data. At the ground station, the RF signal was demodulated by a Sanborn Model 150-2800 preamplifier and recorded on a strip chart by a Sanborn Model 152-100B recorder.

The functioning of the chart recorder at the ground station was checked once each day. An audio oscillator was used to generate frequencies corresponding to those produced by the SCO for input voltages from -2.5 to +2.5 volts in 0.5-volt steps and the recorder pen deflections at voltages through this range were checked for accuracy. The results of these daily calibration checks were reported to the TIROS Control Center and to AED.

In addition to the daily calibration check of the ground equipment, calibration checks of the entire subsystem were made at the beginning and end of each pass, as part of the normal telemetry readout procedure. Before a pass, each recorder channel was calibrated at 1300 and 1200 cps. The precalibration marks were recorded at the beginning of the Sanborn recording for that pass. During the pass the telemetry cycle started automatically when the satellite was interrogated, taking approximately 30 seconds for the 39 telemetered parameters to be transmitted and recorded. Table VII-1 lists the telemetered parameters. The first six parameters were calibration voltages, which provided a check of the SCO frequency deviation through the -2.5 to +2.5-volt range.

The slight frequency drift caused by aging of components and variations in temperature and operating voltages was corrected by the use of this on-board calibration system. The actual deflections of the first six telemetry points were plotted against the prelaunch nominal deflections. This plot provided a calibration curve for converting the remaining 33 points from actual deflections to corrected deflections. Immediately after the completion of each telemetry transmission, a second calibration (post-calibration) was made to check the response of the telemetry-recording system. After post-calibration was completed, a transparent standard-overlay chart was placed over the recorder strip chart to locate any extreme or unusual indications.

The same calibration circuit used for TIROS IV was used on TIROS V.

The beacon transmitters were also identical to those used on TIROS IV. The transmitters were designed to operate at 136.23 and 136.92 Mc and to provide an output power of at least 50 milliwatts. The measured output of the TIROS V beacon transmitters during qualification testing was 65 milliwatts, exceeding the design minimum by 15 milliwatts.

B. PERFORMANCE EVALUATION

The TIROS V telemetry and tracking subsystem operated reliably, providing strong beacon signals and a great quantity of useful telemetry data to the CDA stations. The high degree of accuracy obtained during the TIROS IV program was maintained by the TIROS V subsystem. This accuracy is attributable to continued improvement in the ability of the station personnel to interpret the telemetry data, as well as to the reliable performance of the subsystem.

The performance of the beacon transmitters was highly satisfactory throughout the operational life of the satellite. Pass summaries and verbal reports from the tracking stations have indicated that there was little if any decrease in the output levels of the beacon transmitters with time. The signal levels of these transmitters were continually above the levels predicted for a 50-milliwatt output. This is attributable to the fact that the output power, measured during the environmental test cycle, was at least 30 percent greater than the specified minimum.

TABLE VII-1. TELEMETERED PARAMETERS

Telemetry Switch Position No.	Parameter (136.23-MC Beacon)	Parameter (136.92-MC Beacon)
1	Calibration: Zero Volt	Calibration: Zero Volt
2	Calibration: -0.5 Volt	Calibration: -0.5 Volt
3	Calibration: -1.0 Volt	Calibration: -1.0 Volt
4	Calibration: -1.5 Volts	Calibration: -1.5 Volts
5	Calibration: -2.0 Volts	Calibration: -2.0 Volts
6	Calibration: -2.5 Volts	Calibration: -2.5 Volts
7	"X" String Battery Output: -28 Volts	"X" String Battery Output: -28 Volts
8	"Y" String Battery Output: -28 Volts	"Y" String Battery Output: -28 Volts
9	"Z" String Battery Output: -28 Volts	"Z" String Battery Output: -28 Volts
10	Main Load Buss: -28 Volts	Main Load Buss: -28 Volts
11	Regulated -24.5 Volts, System No. 1	Regulated -24.5 Volts, System No. 1
12	Regulated -24.5 Volts, System No. 2	Regulated -24.5 Volts, System No. 2
13	Regulated -13.0 Volts, System No. 1	Regulated -13.0 Volts, System No. 1
14	Regulated -13.0 Volts, System No. 2	Regulated -13.0 Volts, System No. 2
15	Vertical Sync Pulse, Clock No. 2	TV Xmtr Power Converters, Systems 1 and 2
16	Horizontal Sync Pulse, Clock No. 2	Temperature ‡, Base, at 130° location
17	Vertical Sync Pulse, Clock No. 1	TV Xmtrs Drive Voltage, Systems 1 and 2
18	Horizontal Sync Pulse, Clock No. 1	Temperature †, Base, at 130° location
19	Vidicon High Voltage, Systems 1 and 2	Vidicon High Voltage, Systems 1 and 2
20	Temperature ‡, Base, at 130° location	Temperature*, Base, at 130° location
21	Fil. and Focus Current, Vidicon No. 1	Fil. and Focus Current, Vidicon No. 1
22	Fil. and Focus Current, Vidicon No. 2	Fil. and Focus Current, Vidicon No. 2
23	"Home" Position of Rocket Switch	"Home" Position of Rocket Switch
24	Temperature*, Inner Top Skin at 3" radius	Solar Cell Array Output Voltage
25	Temperature*, Inner Top Skin at 12" radius	Temperature ‡, TV Camera No. 2
26	Solar Cell Array Output Voltage	Temperature ‡, TV Xmtr No. 1
27	Temperature †, Base, at 130° location	Temperature ‡, Beacon Xmtr No. 2
28	500 cps Converter for Tape Recorder No. 1	500 cps Converter for Tape Recorder No. 1
29	500 cps Converter for Tape Recorder No. 2	500 cps Converter for Tape Recorder No. 2
30	Temperature*, Side Panel No. 2	Temperature ‡, Clock No. 2
31	Temperature*, Solar Cells at 3" radius	Temperature ‡, Battery Package
32	TV Xmtr Power Converters, Systems 1 and 2	Vertical Sync Pulse, Clock No. 2
33	Temperature*, Base, at 130° location	Horizontal Sync Pulse, Clock No. 2
34	TV Xmtrs Drive Voltage, Systems 1 and 2	Vertical Sync Pulse, Clock No. 1
35	Temperature ‡, TV Camera No. 2	Horizontal Sync Pulse, Clock No. 1
36	Temperature ‡, TV Xmtr No. 1	Temperature*, Inner Top Skin, at 3" radius
37	Temperature ‡, Beacon Xmtr No. 2	Temperature*, Inner Top Skin, at 12" radius
38	Temperature ‡, Clock No. 2	Temperature*, Side Panel No. 2
39	Temperature ‡, Battery Package	Temperature*, Solar Cells, at 3" radius
40	"Home" Position	"Home" Position

* Temperature Sensor Range: -30 to +100°C

‡ Temperature Sensor Range: +10 to +40°C

† Temperature Sensor Range: -20 to +10°C

The subcarrier oscillators, which are integral to the beacon transmitters, appeared to operate normally as evidenced by the continued reports of good telemetry data received at the ground station. Table VII-2 lists the measured input voltages to the beacon-transmitter SCO for the calibration positions of the telemetry switches.

TABLE VII-2. MEASURED TELEMETRY CALIBRATION VOLTAGES (INPUTS TO SUBCARRIER OSCILLATORS)

Telemetry Switch Position	Calibration Voltages	
	136.23 Mc Beacon	136.92 Mc Beacon
1	0.000	0.000
2	-0.506	-0.506
3	-1.011	-1.011
4	-1.516	-1.516
5	-2.021	-2.021
6	-2.525	-2.525

The telemetry calibration voltages were accurate and stable during the entire period of satellite operation, indicating that the input impedances of the two beacon transmitters did not change or load the voltage-divider circuit excessively. During TIROS V operation, it was observed that the deflections of the ground station recorders remained constant (linear) between the 0- and 2-volt levels and that the voltage-to-deflection ratio remained very close to 1 volt per 10 millimeters. The minus 2.5-volt point was observed to vary by ±1 millimeter about the 25-millimeter position, but this error is believed to have been caused by a non-uniformity which occurred in the Sanborn recorder when it was near its maximum deflection point.

The telemetry switches were identical to those used on TIROS IV and the telemetered data received during the operational life of the satellite gave full evidence of the satisfactory operation of these switches. The telemetry chart recordings indicated that the stepping rate of the switches was in agreement with the specified stepping rate.

Because the telemetered data were substantially in agreement with expected values, an extensive evaluation of the telemetry sensing devices was not made. The two values which did not agree with the expected values were: (1) the telemetered value of -25.8 volts for the power-supply battery on day 291 (this is discussed in detail in Section XI) and (2) the occasional telemetering of indicated temperatures below the range of the 0 to 40°C sensors.

The first report of telemetry below the lower limit of the 0 to 40° C temperature sensors occurred on February 21, during orbit 3545. The points involved were (1) Clock 2 [data from both beacons], (2) Battery Package [data from both beacons], (3) TV Transmitter 1 [data from the low frequency beacon only], and (4) Beacon Transmitter 2 [data from the low frequency beacon only]. All of these points are telemetered at the end of the telemetry readout; thus the abnormal values consistently appeared 22 to 24 seconds after the start of the telemetry readout. Investigation disclosed that these apparently low values coincided with the turn-on of the transmitter power converter for system No. 1

Further investigation of this problem disclosed that these values occurred only when a program of direct camera sequence I, camera 2, with an elapsed time of 1.0 minute was followed by a 1N playback command. This is an unusual program and had never been used prior to February 21, 1962.

The telemetry sensor and related circuits, diagrammed in Figure VII-1, show that an increase in voltage is to be expected if both TV transmitter converters are turned on at the same time. This increase in the voltage supplied to the temperature sensor then appears as an abnormally low temperature reading.

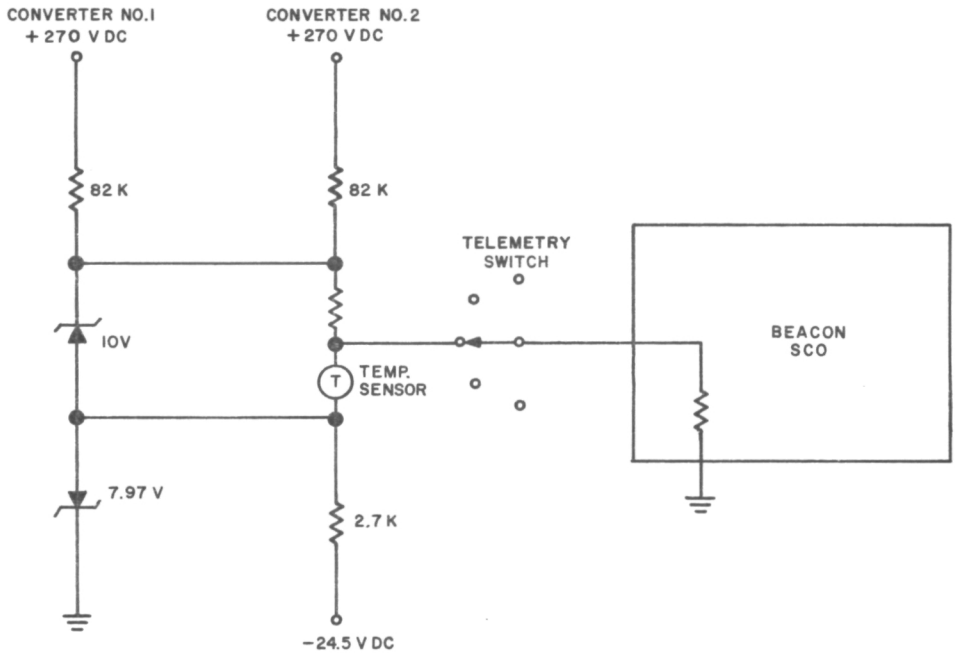


Figure VII-1. Telemetry Temperature Sensor, Schematic Diagram

The use of the 1N playback command in the program was started in order to provide a 235-Mc signal on which to lock the automatic tracking circuits of the medium-gain antennas in use at that time. The corrective action taken was to stop using the 1N command in the programs. This immediately eliminated the abnormal temperature readings and they did not appear again during the operational life on the TIROS V satellite.

VIII. REFERENCE INDICATOR SUBSYSTEMS

A. INTRODUCTION

The reference-indicator subsystems comprised the north-indicator subsystem and the attitude-indicator subsystem. These two subsystems are considered collectively because they both supplied data required for identifying cloud-picture orientation. The north-indicator subsystem, consisting of nine solar-cell sensors and associated electronics, provided data from which the north direction of each TV picture could be determined. The attitude-indicator subsystem, consisting of an IR sensor (horizon scanner) and associated electronics, provided data from which the attitude of the satellite's spin axis could be determined.

B. FUNCTION

1. Attitude-Indicator Subsystem

The attitude-indicator subsystem used on TIROS V was essentially the same as that used on the previous TIROS satellites with the exception that the infrared-sensor unit (horizon scanner) was positioned so that its sensitive axis was at an angle of 70 degrees with respect to the top of the satellite's spin axis. On the previous satellites, the sensitive axis was perpendicular to the spin axis. This subsystem provided data to the ground stations from which the attitude of the satellite's spin axis could be computed. The data was derived from the output of an infrared-sensor unit which scanned the earth and space as the satellite rotated. Heat radiation from the earth caused an electrical output pulse from the sensor during the period in which it scanned the earth. This pulse was differentiated and amplified, and then applied as a modulating signal to the telemetry subcarrier oscillators for transmission by the beacon transmitter to the CDA ground stations.

The attitude information and the telemetry data time-shared the 136-Mc beacon channel. Transmission of the attitude information was continuous except when interrupted for 40 seconds on each orbit by the sending of the telemetry data.

The attitude-indicator subsystem basically consisted of a narrow-field, infrared-sensing bolometer and an amplifying and differentiating circuit (intermediate electronics). The sensor had a 1.6-degree by 1.6-degree square field-of-view, and it was mounted with its optical axis at an angle of 20 degrees with respect to the satellite's baseplate. The sensor had a time constant of 2.0 milliseconds, and a spectral response between 7 and 30 microns which fell off sharply at wave lengths shorter than 7

microns. The spectral response and time constant were chosen so that uniform and accurate response occurred whenever the field-of-view included the earth; the sensor was oriented in such a manner that during the operating period it would never view the sun if attitude variations were of the type predicted. Although no damage would result if the sensor were directly exposed to the sun, such an exposure would produce a spurious output. Varying illumination and reflectivity on the surface of the earth would also generate spurious signals, because the reflected radiation is principally in the wave-length bands to which the sensor responded; however, these signals were cancelled at the ground stations by specially designed inhibit circuits.

The electrical output of the sensor was a trapezoidal wave. In order to avoid stability problems with either low-frequency or d-c amplifiers, and in order to eliminate drift caused by changing ambient temperature, the wave was differentiated and amplified by the intermediate electronics before being transmitted from the satellite.

At the ground station, the attitude data was fed to the attitude-pulse selector. The attitude-pulse selector separated the valid leading and trailing edges of the earth-scan pulse from spurious amplitude changes caused when cloud transitions were scanned. Subsequently, the leading edge of a valid pulse was developed into a pulse representing a sky-earth transition and the trailing edge of a valid pulse was developed into a pulse representing an earth-sky transition. These two pulses were then applied to a digital time-measuring device to measure the interval between the sky-earth transition and the following earth-sky transition. The measured time interval was recorded by punching a paper tape in a standard teletype format. The data thus recorded was later processed to determine the nadir angle of the satellite's spin axis corresponding to the earth-scan interval.

2. North-Indicator Subsystem

The north-indicator subsystem provided electrical data for the determination of the satellite's orientation angle (i.e., the angle in the plane of the satellite's baseplate between a zero-reference radial of the satellite and the bearing of the sun at the beginning of each picture) and thereby, the orientation of the transmitted TV picture. This data was transmitted to the ground stations by the TV transmitters. The satellite orientation data was used in conjunction with data from the ephemerides to determine the north direction of the pictures transmitted from the satellite.

The nine sun-angle sensor units formed the first link in the data chain that provided data from which the north-direction information of each TV picture could be determined. Each sensor unit consisted of a sensor cell mounted parallel to the spin axis behind a slit-type aperture in a special housing. The units were radially mounted, 40 degrees apart, around the vertical walls of the satellite housing.

As the satellite rotated, the slits swept across the direct rays of the sun, causing the sensor cells to generate sun-triggered pulses. These pulses triggered coded multivibrators located in the sun-sensor electronics package. Because of the sensor spacing and because of the 9- to 12-rpm spin rate, two of these coded pulses occurred during each 2-second picture read-out. The coding of the multivibrator output pulses was sequenced in such a way that any two consecutive pulses uniquely defined a sun-sensor location. These pulses were amplified, shaped in the sun-sensor electronics package, and applied to the tape-recorder electronics.

In the tape-recorder electronics, the pulses were used to key a 10-kc subcarrier oscillator to provide 10-kc tone bursts with durations equal to those of the input pulses.

If pictures were being taken in the remote mode (i.e., while the satellite was beyond the range of a ground station), the tone bursts were recorded by the tape recorder, along with the corresponding video information, and were stored until the satellite was commanded to "playback". The tone bursts (along with the video information) were then "read back" into the electronics where the tone bursts were again used to key the 10-kc subcarrier oscillator. The output of the oscillator was modulated on the TV carrier for transmission to the ground. When a sequence of direct pictures was being taken, the tone bursts bypassed the tape recorder and were combined with the camera video subcarrier for direct transmission to the ground.

At the CDA ground station the sun-angle information was separated from the video signal by a bandpass filter. The tone bursts were then detected and applied to the sun-angle computer. The computer identified the particular baseplate-referenced sun sensor associated with the coded sun pulses. It then related the occurrence times of these pulses with the initiation of the video subcarrier, and computed the sun angle. The video information and the computed sun-angle data were displayed visually and photographed. The north direction was then determined from the sun-angle data appearing on the photograph and the orbital data corresponding to the time the TV picture was taken.

The basic requirements and the initial development and design of the sun-sensor electronics are described in the TIROS I final report.

C. PERFORMANCE EVALUATION

1. Attitude-Indicator Subsystem

The attitude-indicator subsystem performed satisfactorily throughout the operational period of TIROS V. The only difficulty encountered was the appearance of a "sun-pulse" in the data during the space scan when sunlight reached

the infrared sensor. Although the lens angle is only approximately 2 degrees, it is believed that sunlight falling obliquely on the lens caused lens "flaring", and resulted in energy reaching the sensor. The sun pulses caused no problem in interpretation of the attitude data since the pulse amplitude was considerably smaller than the "sky-earth" or "earth-sky" pulses.

These sun pulses had not been present during operation of TIROS satellites I through IV and their presence in the TIROS V attitude data is attributable to the repositioning of the infrared horizon sensor with respect to the satellite's spin axis. On TIROS I through IV, the view axis of the sensor lay in a plane parallel to the baseplate and was perpendicular to the spin axis. On TIROS V, the view axis was raised 20 degrees above the baseplate to make a 70-degree angle with the top of the spin axis. The sun angle was never large enough during operation of TIROS I through TIROS IV to allow direct sunlight to enter the lens system. However, with the decreased angle between the spin axis and the sensor's optical axis, the TIROS V sensor was susceptible to direct solar energy at sun angles from 45 to 115 degrees, and on many orbits the sun angle exceeded 45 degrees.

As stated previously, the "sun pulses" did not cause any problem in interpreting the attitude data. However, if sun angles as high as 70 degrees were encountered, the sensor might become saturated, making interpretation difficult. For this reason, it is desirable to keep the sun angle below 65 degrees.

Two approaches could be taken to the reduction of the horizon sensor's cone of sensitivity in order to reduce the occurrence of "sun pulses." One approach would be a reduction in the size of the hole in the satellite hat through which infrared energy must pass in order to reach the sensor. The other approach would be to move the sensor closer to the center of the satellite.

2. North-Indicator Subsystem

The north-indicator subsystem functioned normally during TIROS V operation. The three pulse widths of the sun pulses were well within the allowable limits. However, no north indicator data was received on the system No. 1 TV transmissions of remote pictures after July 5, 1962 (orbit 229). The loss of remote north indicator data was caused by a malfunction in the recorder electronics which prevented either the recording or the playback of the data. This problem is discussed in Section IV in connection with tape recorder evaluation.

In order to circumvent this problem, special programming was used to obtain and relate the system No. 2 north indicator data to the system No. 1 remote pictures. The satellite was programmed for simultaneous remote operation of both camera systems. The angular displacement of the cameras during the interval between the pictures taken by the two systems was determined and was used to correct the system No. 2 sun-angle data for use with the camera No. 1 pictures. This method proved very successful in obtaining accurate data for the remote pictures taken by camera No. 1. Sun-angle data for the direct pictures continued to be present on the system No. 1 TV transmissions.

IX. SATELLITE DYNAMICS CONTROL

A. GENERAL

The four devices used on the TIROS V satellite to provide dynamics control were essentially the same as their counterparts on previous TIROS satellites. These devices were: (1) a tuned energy-absorbing mass called the TEAM precession-damping mechanism; (2) the "Yo-Yo" de-spin mechanism; (3) the spin-up rockets; and (4) the magnetic attitude control. Complete descriptions of the TEAM mechanism, the Yo-Yo mechanism, and the spin-up rockets may be found in the TIROS I final report. The magnetic attitude control is fully described in the TIROS II final report.

B. PERFORMANCE EVALUATION

1. TEAM Precession-Damping Mechanism

The TEAM mechanism reduced satellite nutation by converting the energy of nutation into heat without changing the total momentum of the system. To accomplish this, small traveling masses mounted on curved monorails were released at the time of satellite separation from the third-stage rocket, and permitted to move freely along the monorails. The monorails were positioned and oriented so that nutation of the satellite forced the movement of the masses. The system was mechanically tuned to provide maximum conversion of nutational motion into motion of the masses. As the masses traveled along the monorails, some of their kinetic energy was converted into heat because of friction between the monorails and the trollies on which the masses were mounted. The masses continued to move along the rails, first in one direction and then in the other, until satellite nutation was reduced to a very small value.

The TEAM precession-damping mechanism performed extremely well on TIROS V, rapidly reducing the nutation of the satellite to a small value not only after separation of the satellite from the third-stage rocket, but also after the firing of each pair of spin-up rockets.

2. De-Spin Mechanism

The satellite de-spin mechanism was a "Yo-Yo" device of essentially the same design as was used on all of the previous TIROS satellites. The two de-spin masses weighed a total of 575 grams. This value was selected to produce a theoretical de-spin ratio (ratio of final spin rate to initial spin rate) of

0.078, based on a measured moment of inertia about the spin axis of 159.00 pound-inch-seconds^2. The actual de-spin ratio of TIROS V was 0.070, the initial spin rate being 127 rpm and the final spin rate being 8.66 rpm. This final spin rate was satisfactory, lying within the desired range of 8 to 12 rpm.

The deviation between theoretical and actual de-spin ratios of the TIROS satellites had been investigated previously; the investigation led to the conclusion that such deviations probably resulted from the two percent accuracy inherent in the device used for measuring the satellite's moment of inertia; a one-percent error in this measurement would result in an eight-percent error in the calculated de-spin ratio.

A new bifilar system for measuring the satellite's moment of inertia with an accuracy of 0.5 percent was used for the TIROS V measurement. Thus, the 10-percent de-spin error on TIROS V could not have resulted solely from an inaccuracy in the moment of inertia measurement. Other possible sources of error, such as de-spin cable lengths, radii of the de-spin weights, and accuracy of measuring satellite period-of-revolution, must account for the remaining difference between the theoretical and actual de-spin ratios.

3. Spin-Up Rockets

The satellite's spin rate is gradually reduced in orbit because eddy currents induced in the satellite as a result of its passage through the earth's magnetic field produce fields which tend to oppose the motion of the satellite which gives rise to them (Lenz's Law). As on the previous TIROS satellites, TIROS V was equipped with five pairs of spin-up rockets. Fired in pairs, these rockets increased the satellite's spin rate after it had fallen below the rate required for satellite stability. Each pair of rockets could be fired individually by ground station command to the ignition control circuit when the spin rate was judged to have fallen below that required for proper satellite stability. The total impulse of each rocket was chosen to provide an increase of approximately 3 rpm as the result of the firing of each pair of rockets. (This value of course has varied from satellite to satellite, because of the differing moments of inertia.)

During the engineering phase of the TIROS V program, a study was undertaken to determine if the efficiency and useful life of the rockets could be improved; this study and the consequent modifications made to the rockets used on TIROS V are described in the TIROS V final report. The rockets which evolved from this study were first fired in space during orbit 104 of TIROS V, on June 27, 1962. The first firing increased the satellite spin rate from 8.3 to 11.7 rpm, an increase of 3.4 rpm. A second firing during orbit 3171, after the satellite had been in space for over 220 days, increased the spin rate from 8.0 to 11.29, an increase of 3.29 rpm.

On June 11, 1963, nearly a year after the TIROS V satellite had been launched, all three remaining pairs of spin-up rockets fired (although no intentional spin-up command was transmitted from any of the ground stations). The satellite spin rate increased from 9.1 to 18.6 rpm, a total increase of 9.5 rpm and an average increase of 3.2 rpm per pair of rockets.

The consistent performance of the spin-up rockets on TIROS V, over the long orbital life of the satellite, demonstrated greatly improved stability and longevity.

The firing of three pairs of spin-up rockets between orbits 5115 and 5118 on June 11, 1963, was carefully investigated in an attempt to learn if a control circuit malfunction had caused the firings or if the satellite had responded to transmitted command signals, whether intentional or spurious. Although a number of possible causes were found, no definite conclusion could be reached.

Before orbit 5116, the rocket control switch had been at position 4. (Although the switch is in the home position at launch, the first pair of rockets is not fired until the switch has advanced to position 3; subsequent pairs are fired by advancing the switch one position for each pair. Thus the first two firings of the TIROS V spin-up rockets had left the switch at position 4.) After orbit 5117, the spin rate of the satellite was observed to have increased by more than 9 rpm, although no programming of the spin-up rocket switch had been authorized. Regular programming of the satellite had ceased prior to that time, and thus there was no loss of TV data as the result of the high spin rate. In order to determine how many positions the switch had advanced during the unexplained firings, it was decided to step the rocket switch until it reached the home position. Nine separate rocket firing commands were required to step the 12-position switch to the home position, indicating that the switch had been at position 3 after the unauthorized firings. Thus, during orbits 5116 and 5117, the switch had, in some manner, been caused to advance 11, or some multiple of 11, positions.

Two causes of the rocket firings are possible:

(1) Accidental or intentional programming by one of the ground stations or some other transmitting source.

(2) An internal satellite malfunction.

The Wallops Island, PMR, and AED ground stations all verified that no programming of the spin-up rocket switch had occurred during orbit 5116 or orbit 5117. Accidental command by the launch-support group supporting the TIROS VI operations at Cape Canaveral was not possible since the Cape Canaveral transmitter was not yet in operation on the morning of June 11, 1963 at 0600 hours EST when the satellite passed due east of Cape Canaveral during orbit 5116 or approximately 100 minutes later when the satellite passed west of Florida

during orbit 5117. On the subsequent ascending node the satellite was below the Cape Canaveral horizon. Thus, only a random spurious command or an internal malfunction could have caused the rocket firings.

The circuit that supplies the index signal to the solenoid and the ignition power to the rockets is continually supplied from the batteries. However, power is available to the command circuits only when one of the two K-2 relays is energized. When considering the command logic, this requires that the satellite be under the control of a ground station. Accidental reception of the command sequences seems a remote possibility. To step the rocket switch the indicated number of times would require, first, that the satellite be programmed into an operational mode and, second, that the proper command for rocket fire be transmitted to cause the first stepping of the switch. If this first step were taken, it is possible that interrupted commands could cause the switch to step rapidly at rates up to approximately one step per second. This type of command could also be accomplished if a very weak signal (on the order of 0.2 to 0.4 microvolt) of the proper command tone were received. It should be noted that a complex wave modulation with a harmonic content including the rocket fire tone and one of the operational mode tones could also cause the same operation.

When considering possible malfunctions of elements aboard the spacecraft, two alternatives present themselves. The first is a faulty rocket switch and the second is a circuit malfunction.

The rocket switch shorting deck is of the "make before break" variety. Considering the leakage characteristics of the transistors, the rise time of the index signal could be slow, causing a relatively slow indexing characteristic of the solenoid, and possibly an incomplete index. If the switch were incompletely indexed or if one of the contacts were out of line to the point that the shorting deck could contact two wipers simultaneously, the ignition current would be applied to all the rockets in parallel as shown in Figure IX-1. The shorting deck is connected to terminal-board ground. If the shorting desk is connected to the solenoid ground, and one lead is taken from this point to terminal-board ground, a ground loop is conceivable. The rocket grounds are also taken to terminal-board ground and the "high" sides of the ignition wires are returned to the shorting deck. Assuming five feet of harness length from the rocket switch to terminal-board ground (in accordance with the TIROS V configuration) it is possible to generate several millivolts on the shorting deck, due to the solenoid signal alone. The rockets comprise a load of under 0.1 ohm when six rockets are considered in parallel. The ignition current and solenoid signal are applied to this ground loop. Therefore, it is conceivable that all the rockets could be fired simultaneously if the above conditions are met. Since this malfunction has never occurred before, it is assumed that it did not occur on TIROS V; however, it must remain a possibility.

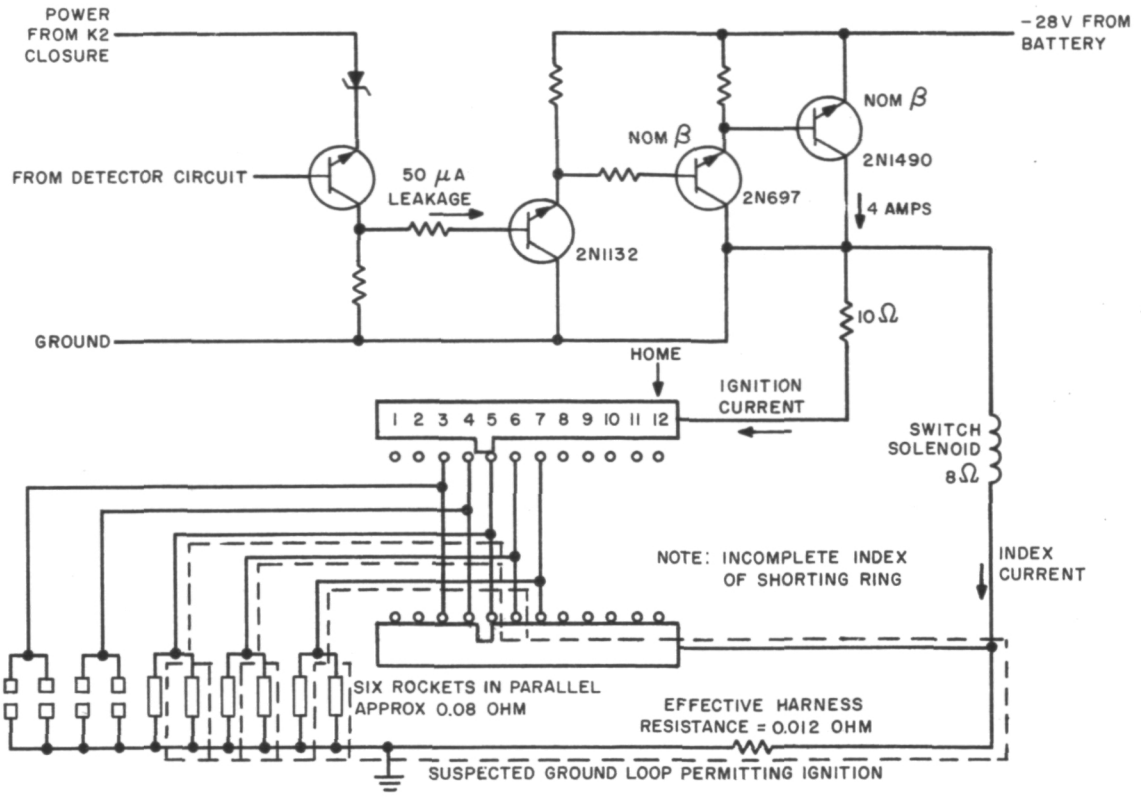


Figure IX-1. Rocket Switch and Switch-Driving Circuit, Schematic Diagram

The possible failure modes of the circuits associated with spin-up command and control can be divided into two distinct areas, (1) failure modes of the index and ignition circuitry and (2) failure modes of the detector circuitry.

An analysis of the index and ignition circuitry leaves very little chance of failure other than degradation of the input transistor. Failures other than this would probably not allow for continued use of the circuit. If the first transistor became leaky to the extent of about 50 microamperes of base current, it would be possible to have erratic stepping of the index switch. Such a failure would not prevent normal programming of the switch. If this were the case, the switch could conceivably index itself further. The transistor might degrade further to the point of beta loss which would prevent further uncommanded stepping. If the above is taken as the answer, it may be concluded that two of the CDA station command steps did not, in fact, index the switch, as it would then take seven, not nine, steps to return to the home position. Alternately, if the leakage were just marginal, the device may have "free run" through eleven positions. This, upon examination, would indicate that the rapid chattering was accomplished by the first stage transistor being loaded and unloaded or just "wandering" through what could be described as the leakage threshold.

Figure IX-2 is a representation of the detector circuit. The 8- and 60-microfarad capacitors used in this circuit were of the wet tantalum type which have, on occasion, displayed erratic behavior. Such devices have been known to short and also to become leaky. In the leaky condition, the apparent capacity increases since a resistance is, in effect, paralleled with the capacitor.

If the 8-microfarad capacitor should become leaky, the audio integration which it performs would be affected by the apparent change in the time constant. However, this time constant is so large in comparison with the period of the audio tone involved that a relatively small effect on the circuit would result. If this capacitor should open, the integration would be performed by the 60-microfarad timing capacitor, increasing the delay time. Should the 8-microfarad capacitor become shorted, the circuit would not work since the timing capacitor could not be charged.

Should the 60-microfarad capacitor become shorted, the threshold of the Q9 transistor could not be reached. If the 60-microfarad capacitor should become leaky, the time delay would be increased.

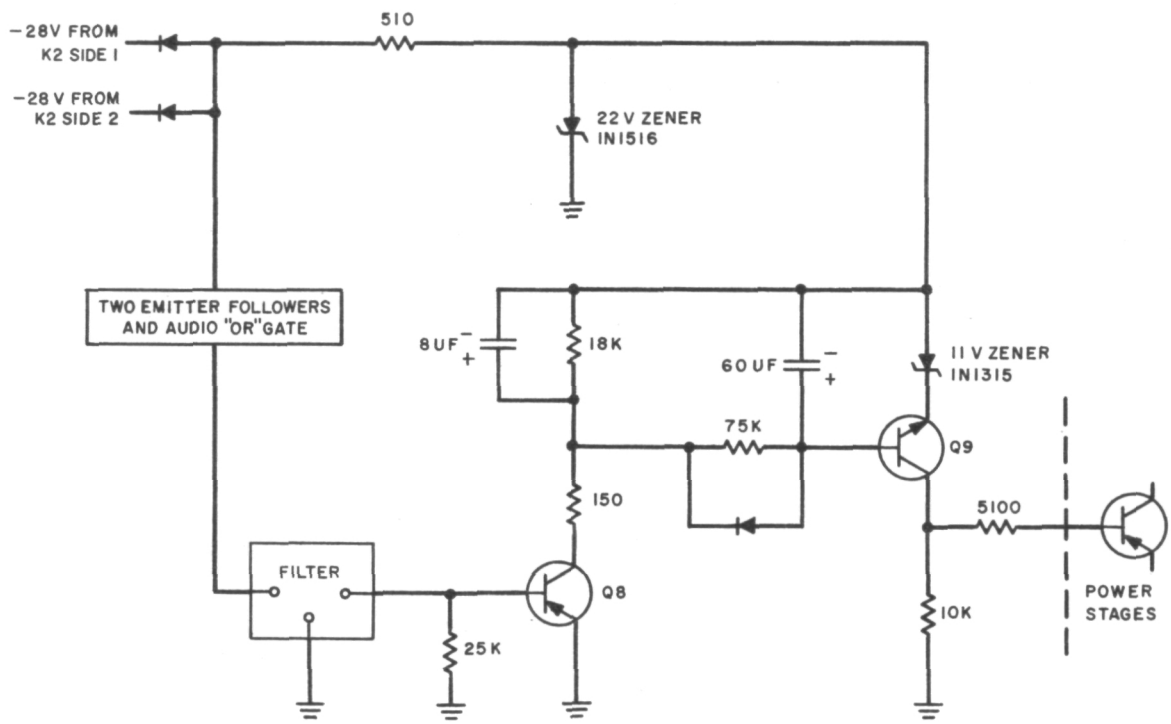


Figure IX-2. Rocket Command Detector Circuit, Schematic Diagram

Also considered were the two zener diodes employed in the circuit. These devices have been known to operate normally most of the time but sporadically to fail to operate or even to become open- or short-circuited.

If the 11-volt zener diode decreased its conduction threshold, the time delay would be decreased. If this diode shorted, the delay would approach zero. If it opened, Q9 could not be switched.

If the 22-volt zener diode reduced its threshold, the delay would increase because the audio output of Q8 would decrease in amplitude while the Q9 threshold, maintained by the 11-volt zener, would remain constant.

If the battery voltage were low and the actual value of the 22-volt zener diode were 10 percent above nominal, a possible way would exist for the rocket switch to be stepped. The detector and delay circuit requires a maximum of approximately 4 milliamperes when Q9 is switched on. At this instant, the 510-ohm resistor drops about 2 V d-c. If the zener is at the high limit indicated above, and if a nominal 0.5 V d-c drop in battery voltage occurs, the supply would have to be approximately 26.5 V d-c (24 + 2 + 0.5), the level indicated in the power drain reports for TIROS V on June 11, 1963, in order for the diode to remain in conduction. When the fire circuit is energized, a high current is required by the output switch. If this is enough to cause even a minor perturbation in the battery voltage, the 22-volt zener may be taken out of conduction and the detection circuit may change its characteristics. If the rocket-fire tone required to start the above sequence is marginal, it is conceivable that Q9 could be switched off and on rapidly. The rocket switch would follow this stepping each time that Q9 came into conduction.

If Q8 were to display some collector-to-emitter leakage, it is remotely possible that the same effect would result. However, it must be remembered that the rocket switch apparently functioned normally after the firings which would not be expected if Q8 were defective.

From the data available, it would seem most likely that a spurious program caused the rocket firing to occur. The most probable internal malfunction which could cause all rockets to fire on one command would be an improper indexing of the rocket switch. Circuit failures are improbable, since the switch apparently was stepped normally on command on subsequent programs. No definite statement can be made as to the exact cause of the rocket firing and no further information can be gained.

4. Attitude Prediction, Measurement, and Control

a. Function

The importance of being able to predict and later to determine and control the satellite's attitude in orbit is apparent when it is understood that TIROS is a space-oriented satellite (its spin-stabilized axis tends to remain fixed in space) and that its TV cameras are fixed in position on the satellite's baseplate. Thus the cameras point toward the earth during a limited portion of each orbit. For useful pictures to be taken, the cameras must point toward the illuminated part of the earth. Also, the view angle of the cameras must not be excessively oblique with respect to the surface of the earth. In order to maintain an adequate power reserve, the satellite's attitude must also permit the solar cells to collect solar energy efficiently during a portion of each orbit. Thus the optimum attitude is a compromise between the conditions for good picture geometry, good illumination of the picture area, and adequate solar energy input.

The ideal attitude for minimum picture distortion would be one in which the cameras would point directly toward the center of the earth as the satellite passed over the area of interest, and the area of interest would be well illuminated. However, since attitude determinations are made principally from inspection of the TV pictures, and since this process is more difficult when the pictures show no angle between the optical axis of the cameras and the surface of the earth, the most desirable attitude is one in which the cameras point about 20 degrees away from the sub-orbital track of the satellite.

Initial 90-day attitude predictions are based on the planned time of launch and on the measured dipole moments of the satellite. These values are incorporated in a computer program which is used in calculating the celestial coordinates (right ascension and declination) of the normal point (point at which a line drawn through the center of the earth and parallel to the satellite's spin axis intersects the surface of the earth). Data from the satellite (attitude data as well as TV pictures) are used in determining the satellite's attitude.

Control over the satellite's attitude is afforded by the magnetic attitude control. This device consists of a coil of wire wrapped around the satellite and a switch, controllable by ground command, that selects the direction and magnitude of current flowing in the coil. This programmed magnetic dipole adds to or subtracts from the satellite's own small residual dipole and affords control over the interaction of the satellite's magnetic field with the earth's magnetic field. Using this programmed control the satellite's attitude can be altered by a maximum of 15 degrees per day. A program of magnetic attitude-control switching is determined in advance of the launching, in order to produce good picture-taking conditions and desirable sun angles during the initial 90-day period.

Before the satellite is launched, the residual magnetism is reduced to a minimum value by the addition of permanent magnets. The residual magnetism is then carefully measured, as are the magnetic moments of the satellite at each setting of the magnetic attitude-control switch.

When the satellite' s attitude in orbit is observed to deviate from the predicted attitude, the data is studied to determine if the deviation is the result of inaccurate determination of the satellite' s attitude, inaccuracy of the measured residual dipole moment of the satellite or an inaccuracy inherent in the computer program. After these possibilities have been evaluated, and if it is decided that a change in predicted attitude is desired, the predicted data is shifted to agree with the observed data or the value of the residual magnetic dipole moment used in computation is changed.

When a change in satellite attitude is desired, to improve the sun angle, the picture geometry, or the scene illumination, the change in dipole moment that will produce the attitude change is calculated and the magnetic attitude-control switch is programmed accordingly.

Beginning with TIROS II, this subsystem has been used with a high degree of success in predicting and controlling the orbital attitudes of the TIROS satellites. As the techniques associated with its use have become more refined, the subsystem has been used with more flexibility, not only to correct the satellite' s attitude in accordance with the initial program but also to achieve new orbital attitudes in order to obtain pictures in areas of interest as they develop.

b. Performance Evaluation

The TIROS V attitude-control subsystem was of essentially the same design as the subsystem used in TIROS II through IV. However, a revised computer program was used for making the initial 90-day predictions of spin-axis motion. This revised program provided increased accuracy by making use of a one-orbit integration interval in place of the five-orbit interval used previously. Subsequent to the first 90-day predictions, the computer program was further revised to provide even greater accuracy in the predictions. This second change was implemented by a higher-speed computer and differed from the initial program in the following ways:

(1) The revised program uses an integration interval of 0.1 orbit, while the initial program used an integration interval of 1.0 orbit.

(2) The revised program provides for calculation of the instantaneous orbital position of the satellite and references this position to a dipole model of the earth' s magnetic field at that position. (The initial program provided for calculation of the average magnetic field during an orbit.)

(3) The revised computer program takes into account the eccentricity of the orbit while the previous program assumed a circular orbit.

Prior to launch, the daytime- and nighttime-standby dipole moments of TIROS V were measured to be 0.4 and 0.5 ampere-turns-meter^2, respectively. Based on these values, paths of spin-axis motion in normal-point right ascension and declination were predicted and plotted for use in establishing picture-taking sequences. However, as in previous TIROS programs, the observed motion of the spin axis was not in full accord with the prelaunch predictions, indicating a difference between the measured and actual dipole moments*. After the actual motion was observed for approximately one week, the actual standby dipole moments were empirically determined to be 0.55 ampere-turns-meter^2 for daytime and 0.655 ampere-turns-meter^2 for nighttime. Based on these values, new predictions of spin-axis motion were made and plotted. These plots are shown in Figures XI-3 and XI-4, sheets 1 through 4.

As indicated on the plots, the MAC switch was first stepped on orbit 213. Additional stepping of the switch was accomplished as necessary to maintain a favorable spin-axis attitude.

By orbit 755, it was apparent that a constant difference existed between the predicted and the observed paths. The predicted coordinates were, therefore, shifted to agree with the observed coordinates. This shift in data is indicated in Table IX-1, as are subsequent shifts to observed data. Also listed in the table is a second set of changes in the values of the satellite' s dipole moments. The need for these changes became apparent some four months after launch. It is believed that they were necessary because of actual changes in the satellite' s residual moments, attributable to long-term exposure to the orbital environment.

Subsequent to the initial 90-day predictions, the new computer and the new computer program were employed and yielded excellent results, as indicated by the limited number of corrections to the predicted attitude data (see Table IX-1). The need for these corrections was attributable to two factors, namely, long-term changes in the satellite' s residual dipole moment (which had not been evident during operation of the previous satellites because of the shorter evaluation periods) and the steep gradients that occur when the setting the the MAC switch is changed to the maximum negative or maximum positive position. It is believed that a further revision of the computer program used in making the predictions would lead to improved accuracy, and thus to fewer corrections in the data. One step toward achieving this aim in the future would be the use of an even shorter integration interval in the predictions that immediately follow stepping of the MAC switch to its extreme negative and positive positions.

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* Differences between the in-orbit and the measured dipole moments are anticipated because of the state of the art in measuring a satellite' s dipole moments. However, the prelaunch measurements and predictions provide a basis for determining the in-orbit values and are, therefore, a vital part of the attitude prediction and control program.

TABLE IX-1. CORRECTIONS TO PREDICTED ATTITUDE DATA

Type of Correction	Orbit No.	Correction To	
		Right Ascension (degrees)	Declination (degrees)
Shift to observed data	755	155.7	35.9
Shift to observed data and change in residual dipole moments	1921	186.5	22.0
		Residuals	
		Daytime:	-0.535 a-t-m^2
		Nighttime:	-0.635 a-t-m^2
Shift to observed data	2424	260.8	29.0
Shift to observed data	3529	None	36.7

The observed data plotted in Figures IX-3 and IX-4 represent an improvement over the observed data for TIROS III and TIROS IV. The TIROS III evaluation indicated that certain patterns in the data could not actually occur and that they were indeed only due to human interpretation of the data. It was believed by those who plotted the observed data that a trend in data would continue long after a change in the MAC switch setting. (Actually, experience has shown that this kind of inertial motion is extremely small and would not be observed.) Working under the assumption that these trends should exist, the Allied Research personnel at the Wallops Island ground station guided the TIROS III data in this direction. The inclusion of the IR subsystem on TIROS IV removed a good deal of the ambiguity in the data. As a result, the TIROS IV data left little room for subjective interpretation and the "inertial trends" mentioned above did not appear. In the case of TIROS V, the data was, in general, quite good, clearly reflecting the experience gained during the previous programs.

There are, however, improvements which could be made to further increase the usefulness of the data. The present process of attitude determination rests heavily on photoanalysis. The Fujita method* determines the right ascension and declination from the known relationships between attitude, nadir angles and the earth's horizon. The spin-axis point is determined for each usable frame. A cluster of

* The Fujita method for determining satellite attitude is described in A Technique for Precise Analysis for Satellite Data; Tetsuya Fujita; Meteorological Satellite Laboratory Report No. 14, Vol. I, Photogrammetry; Jan. 1963.

these points from a complete orbit is then plotted and reduced to one point. The associated NON (minimum nadir angle) and TOT (time of minimum nadir angle) are then obtained. This portion of the analysis is done by the Weather Bureau which in turn forwards the NON and TOT values to Allied Research personnel. The error in right ascension and the error in declination could be as great as ±2 degrees, and would be dependent on picture quality, landmarks, and nadir angles (earth horizons). The values of NON and TOT are plotted along with all other inputs (e.g., horizon sensor data). Smooth curves are fitted to the data. New NON and TOT values are obtained from these smooth curves and the right ascension and declination are then computed. Since there is no detailed error analysis for the above process it can only be assumed that data showing one decimal place imply an error of ± 0.5 degree. This is, however, probably not always the case. It is therefore suggested that a study be made to determine the errors associated with the data. Until this is done, it will be assumed that errors of ± 2.0 degrees are not unrealistic during troublesome periods. Under normally good conditions, an error of ± 0.5 degree will be assumed.

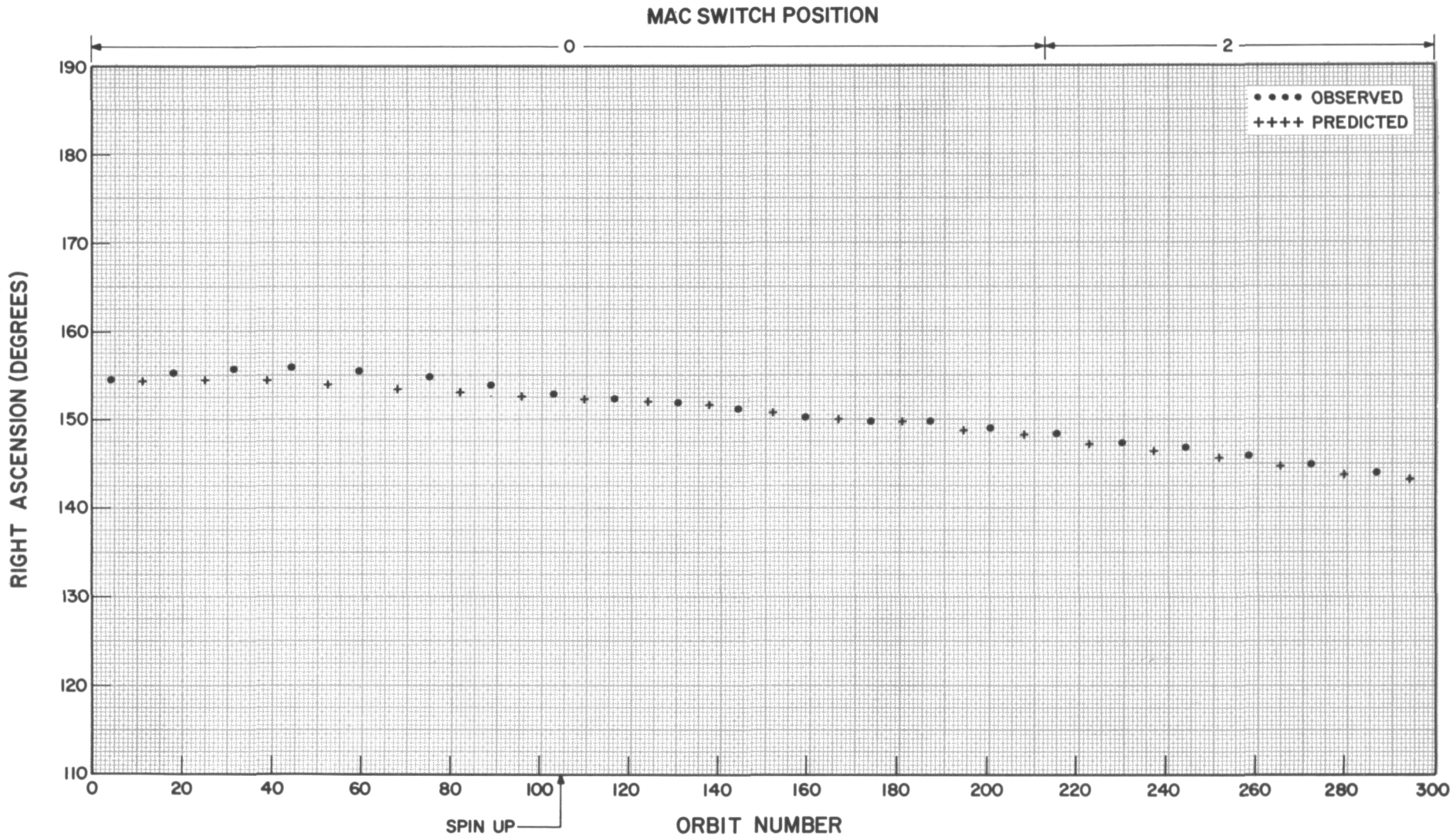

Figure IX-3. Normal Point Right Ascension versus Orbit Number (Sheet 1 of 16)

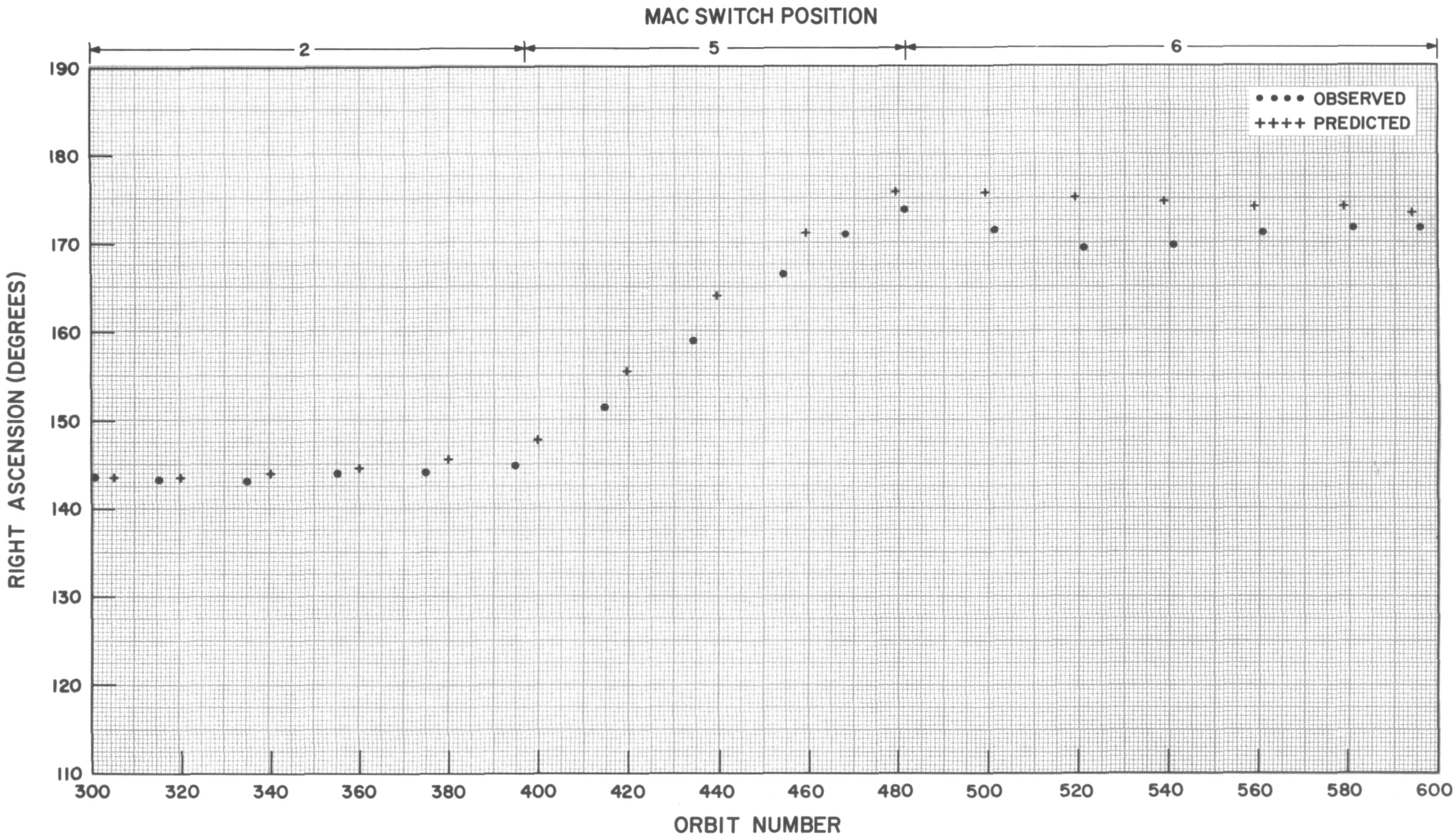

Figure IX-3. Normal Point Right Ascension versus Orbit Number (Sheet 2 of 16)

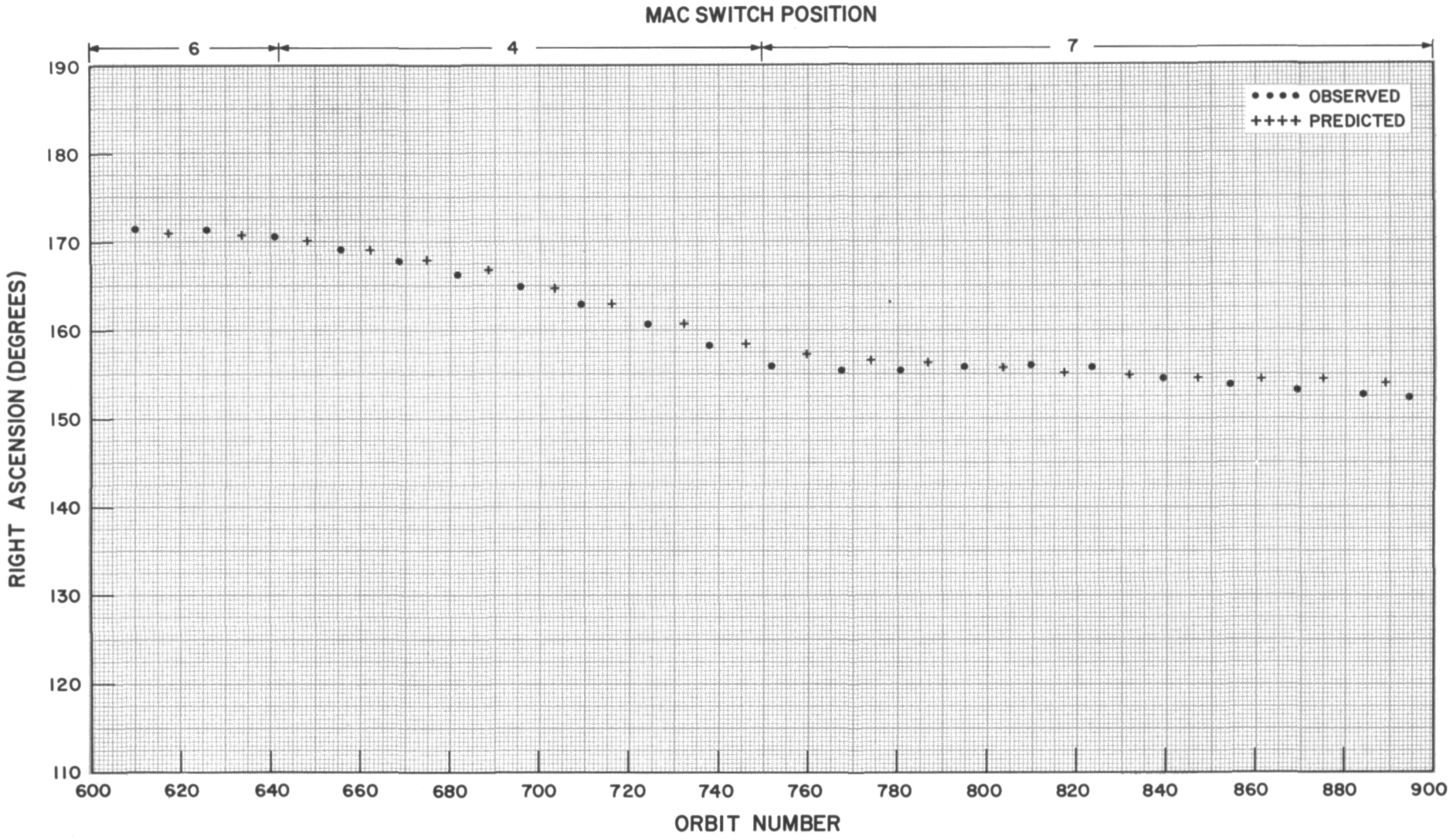

Figure IX-3. Normal Point Right Ascension versus Orbit Number (Sheet 3 of 16)

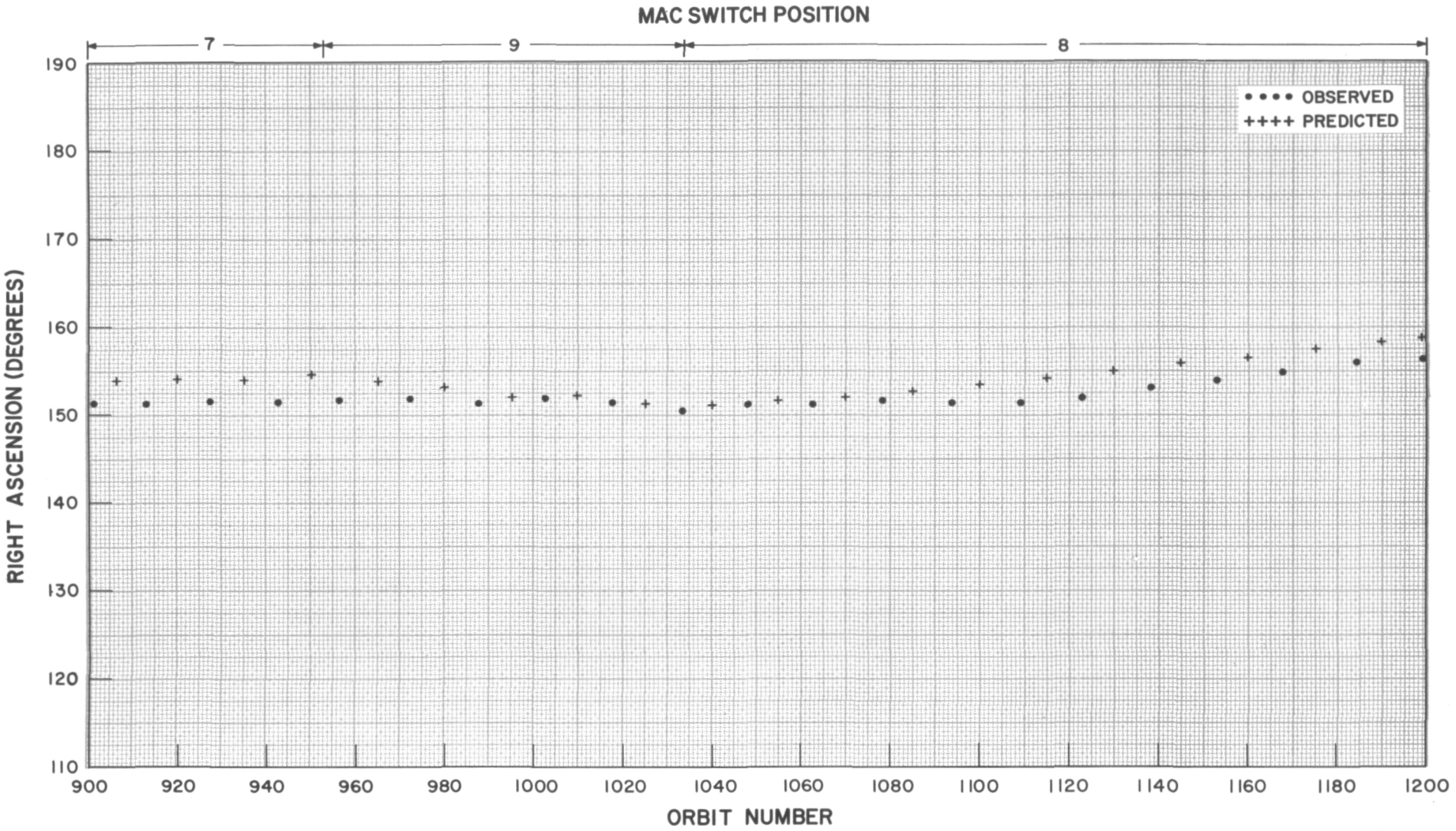

Figure IX-3. Normal Point Right Ascension versus Orbit Number (Sheet 4 of 16)

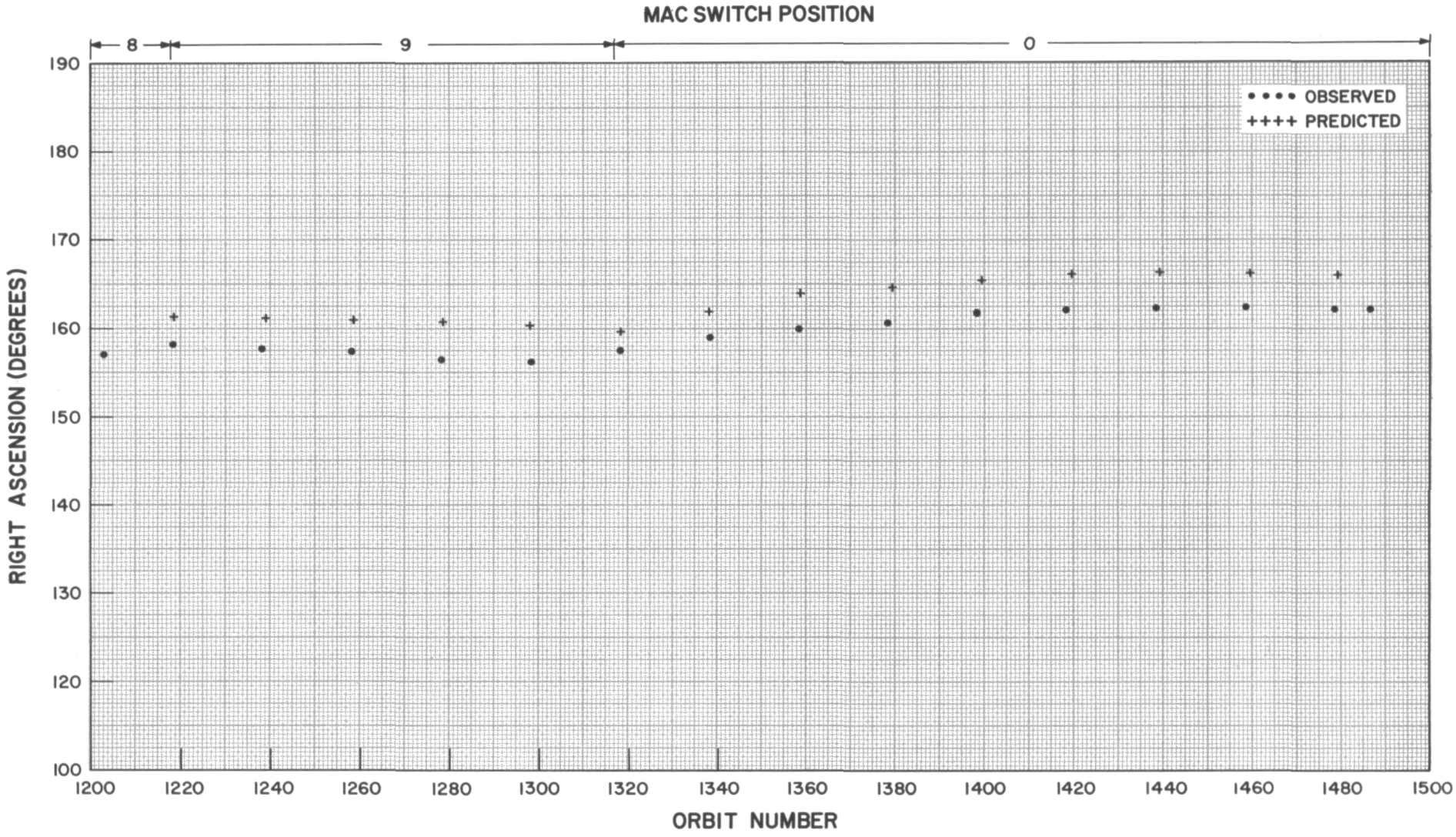

Figure IX-3. Normal Point Right Ascension versus Orbit Number (Sheet 5 of 16)

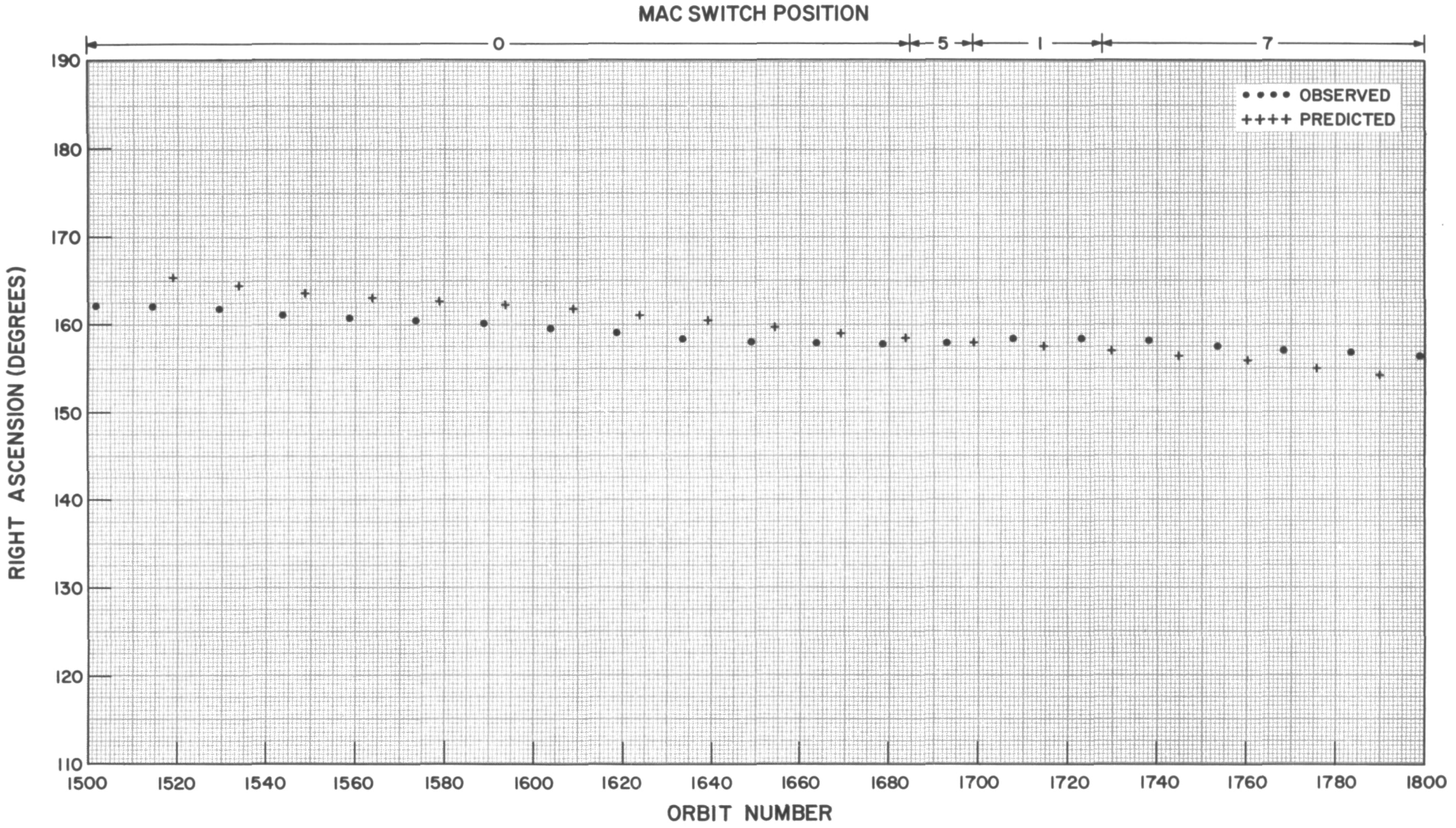

Figure IX-3. Normal Point Right Ascension versus Orbit Number (Sheet 6 of 16)

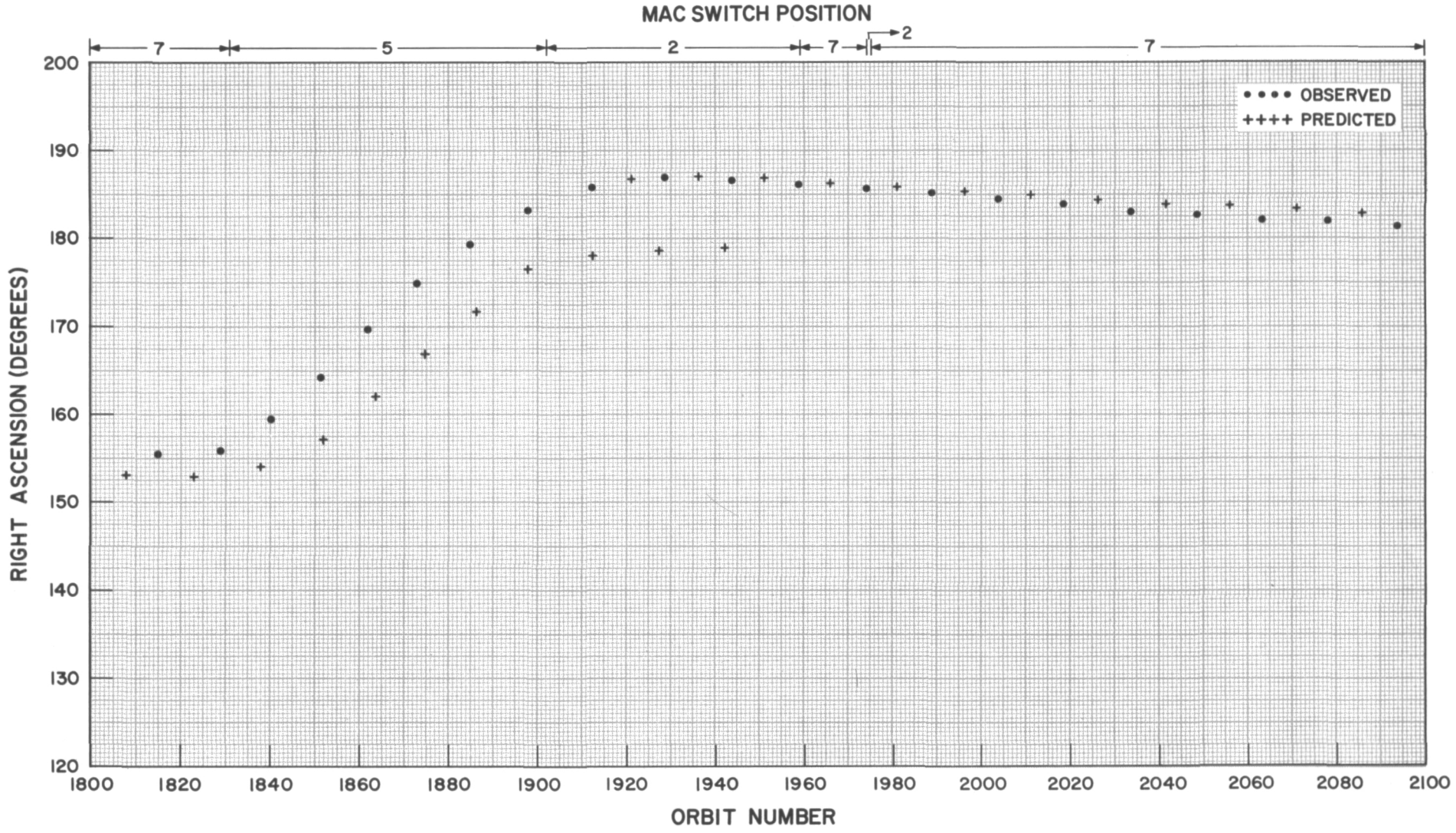

Figure IX-3. Normal Point Right Ascension versus Orbit Number (Sheet 7 of 16)

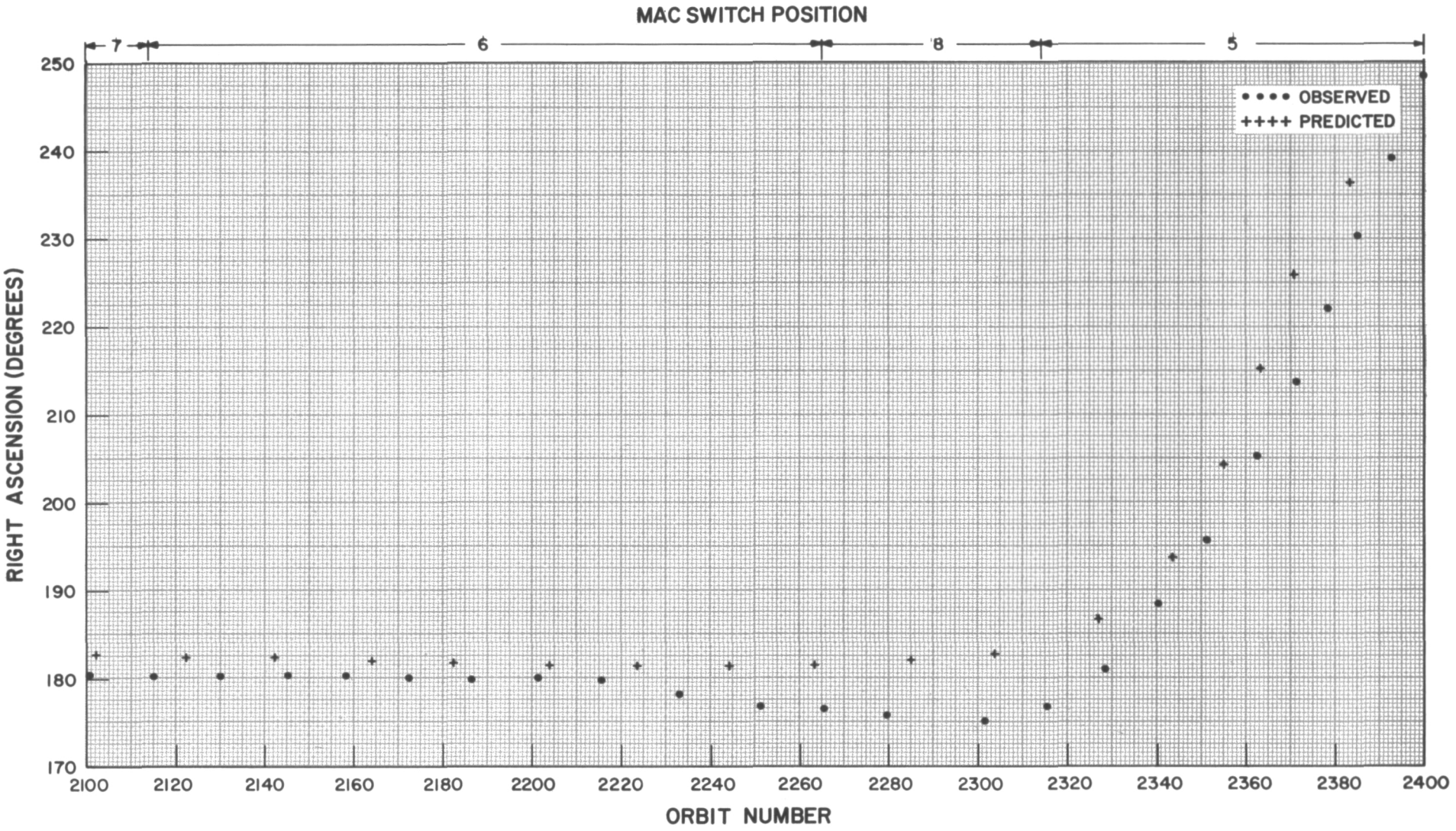

Figure IX-3. Normal Point Right Ascension versus Orbit Number (Sheet 8 of 16)

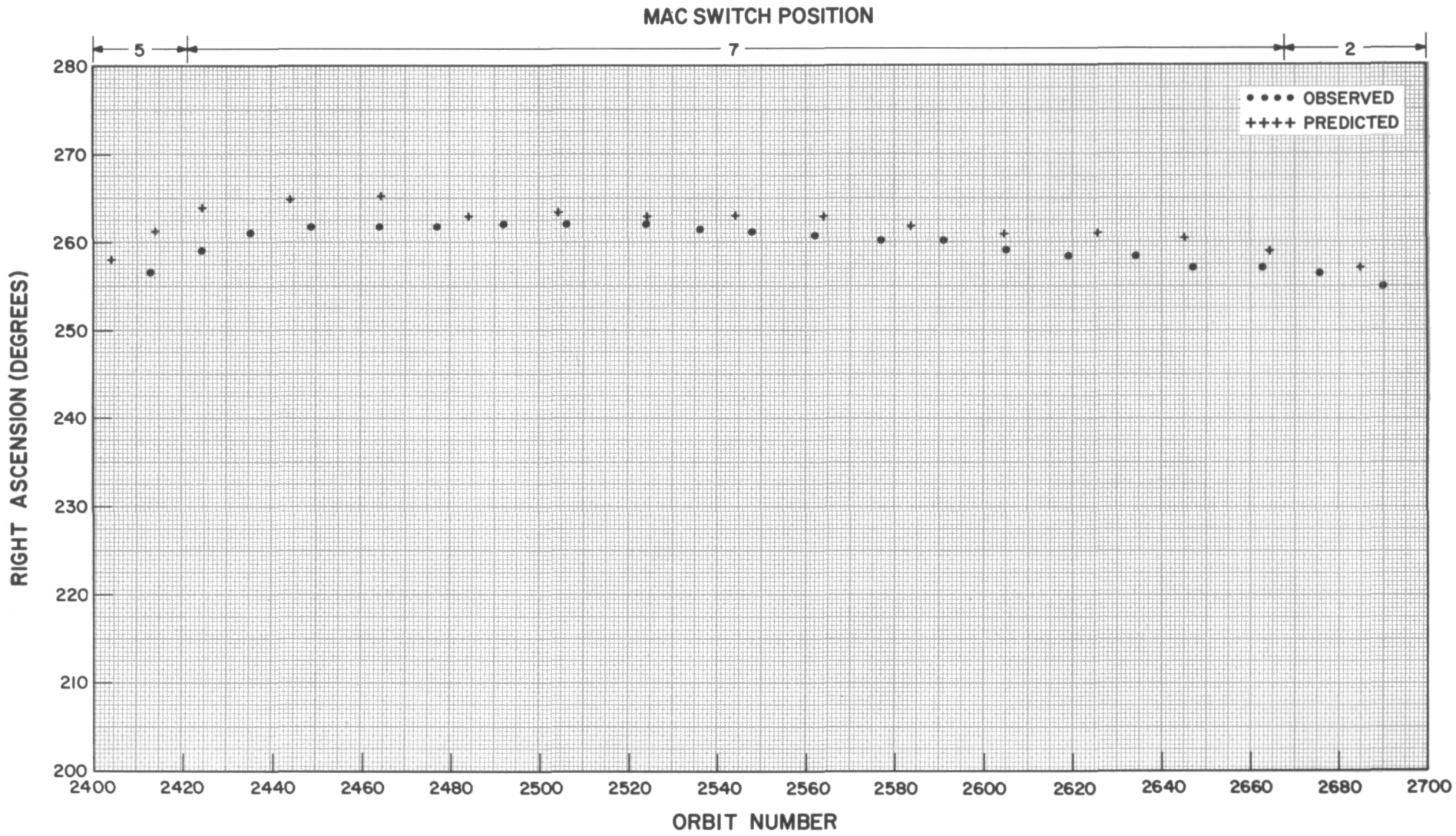

Figure IX-3. Normal Point Right Ascension versus Orbit Number (Sheet 9 of 16)

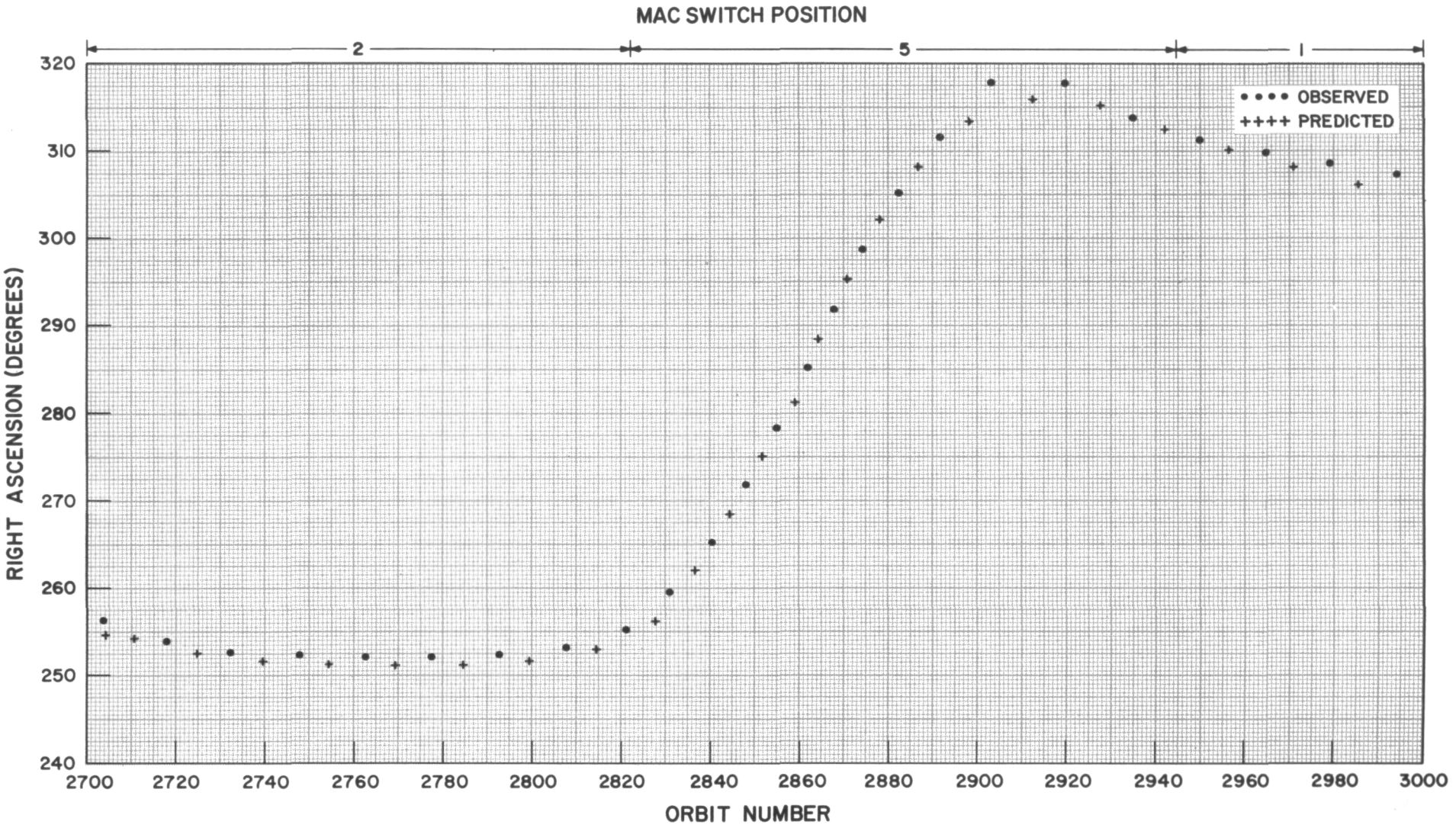

Figure IX-3. Normal Point Right Ascension versus Orbit Number (Sheet 10 of 16)

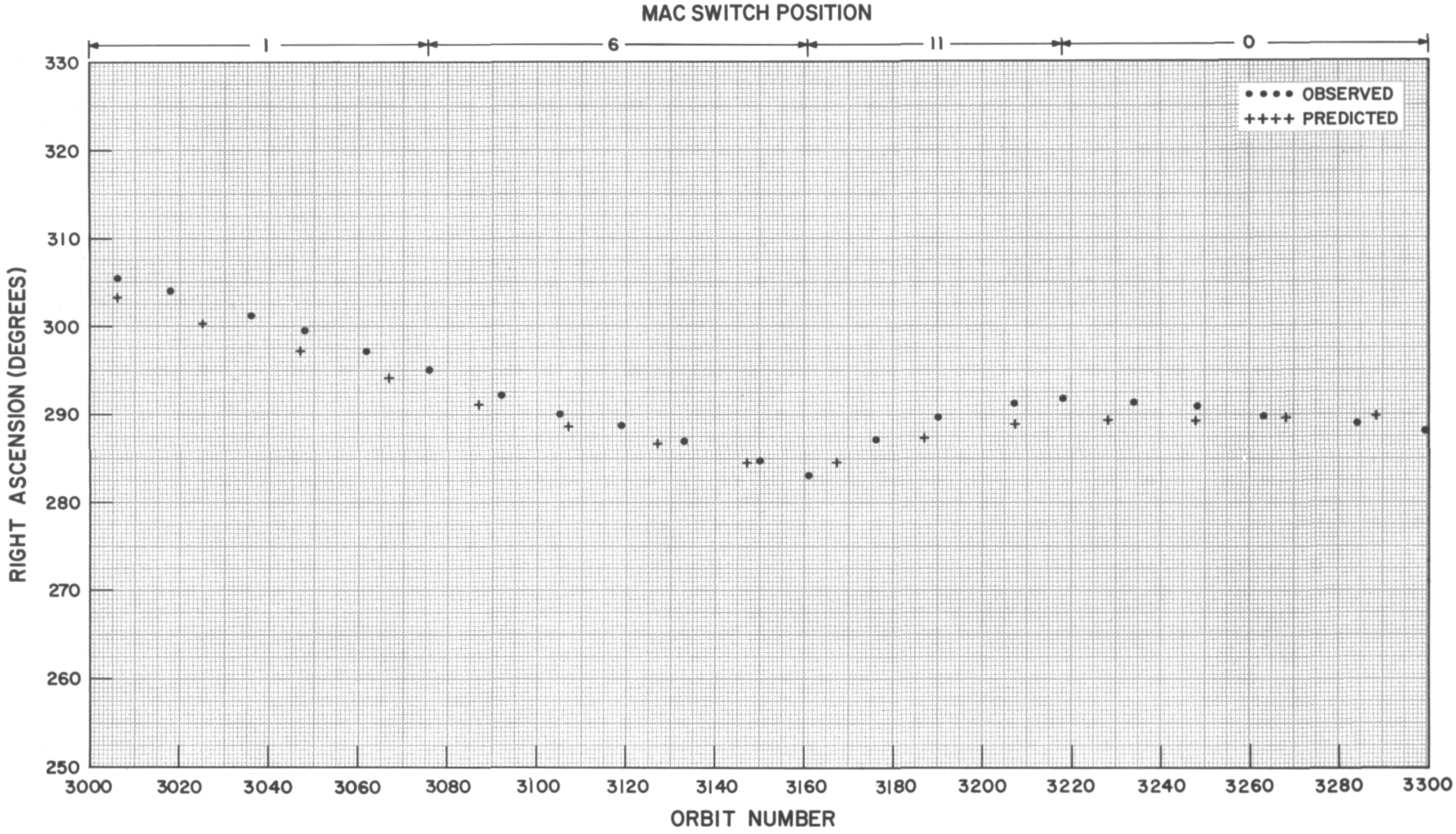

Figure IX-3. Normal Point Right Ascension versus Orbit Number (Sheet 11 of 16)

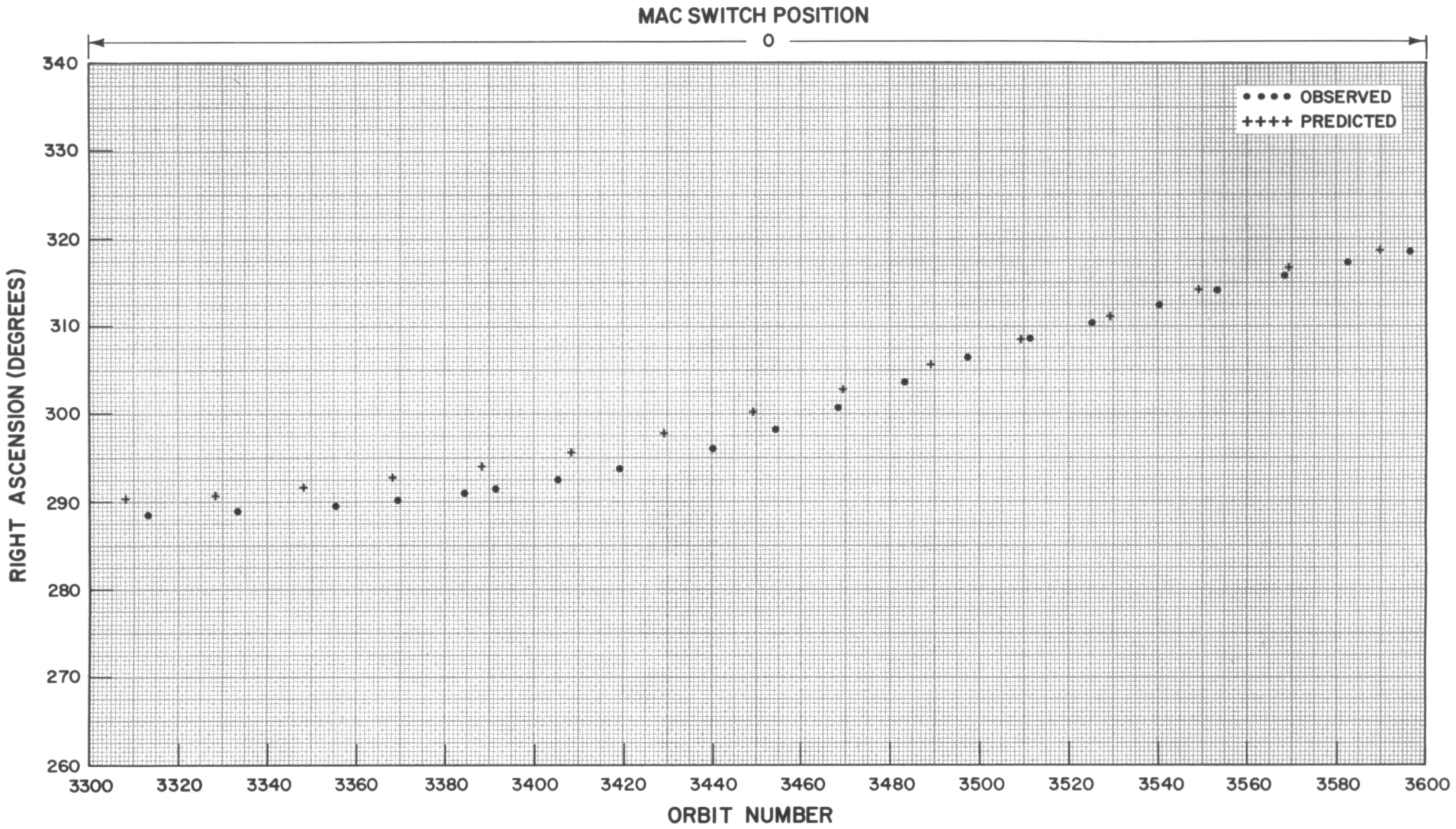

Figure IX-3. Normal Point Right Ascension versus Orbit Number (Sheet 12 of 16)

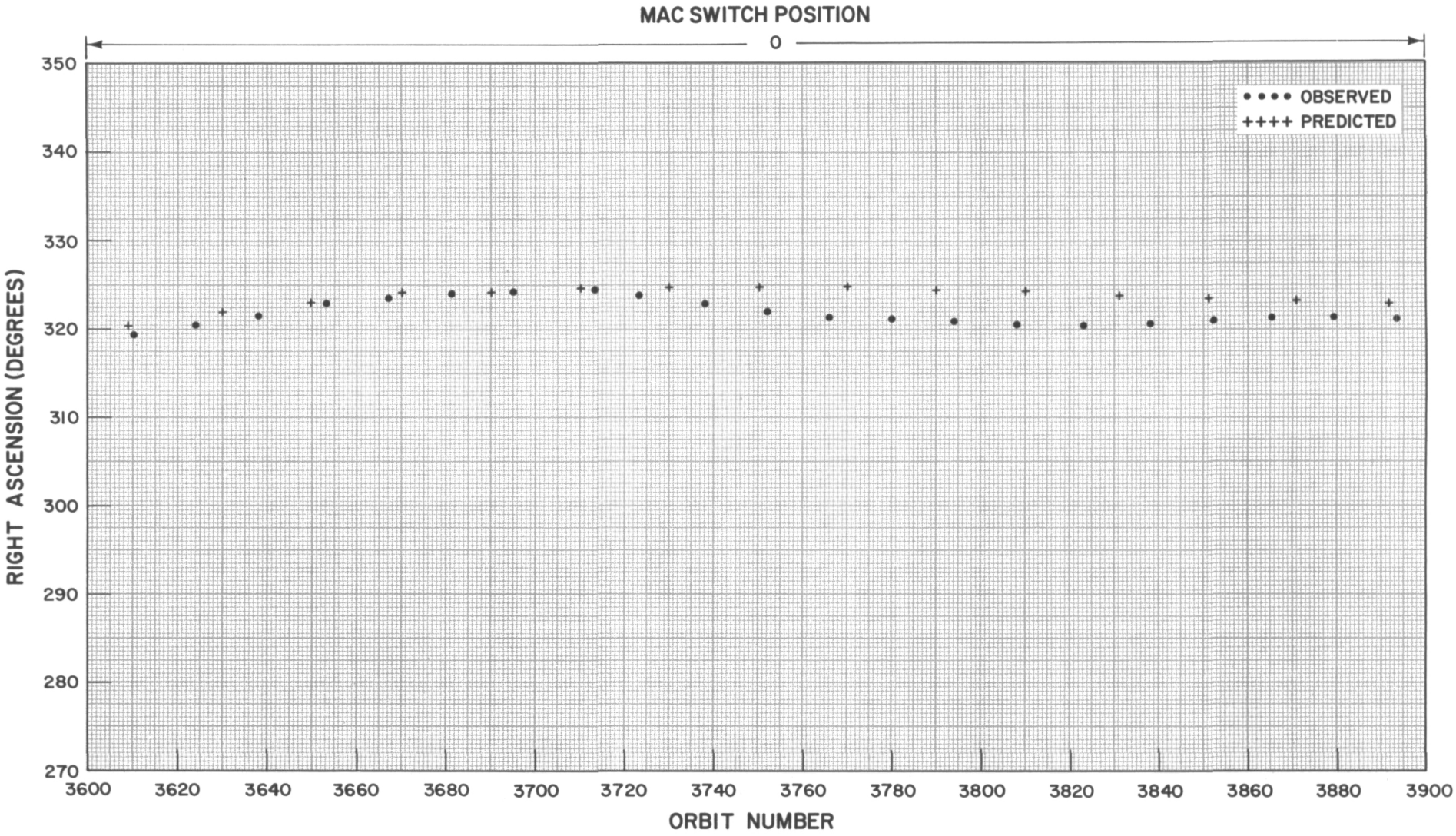

Figure IX-3. Normal Point Right Ascension versus Orbit Number (Sheet 13 of 16)

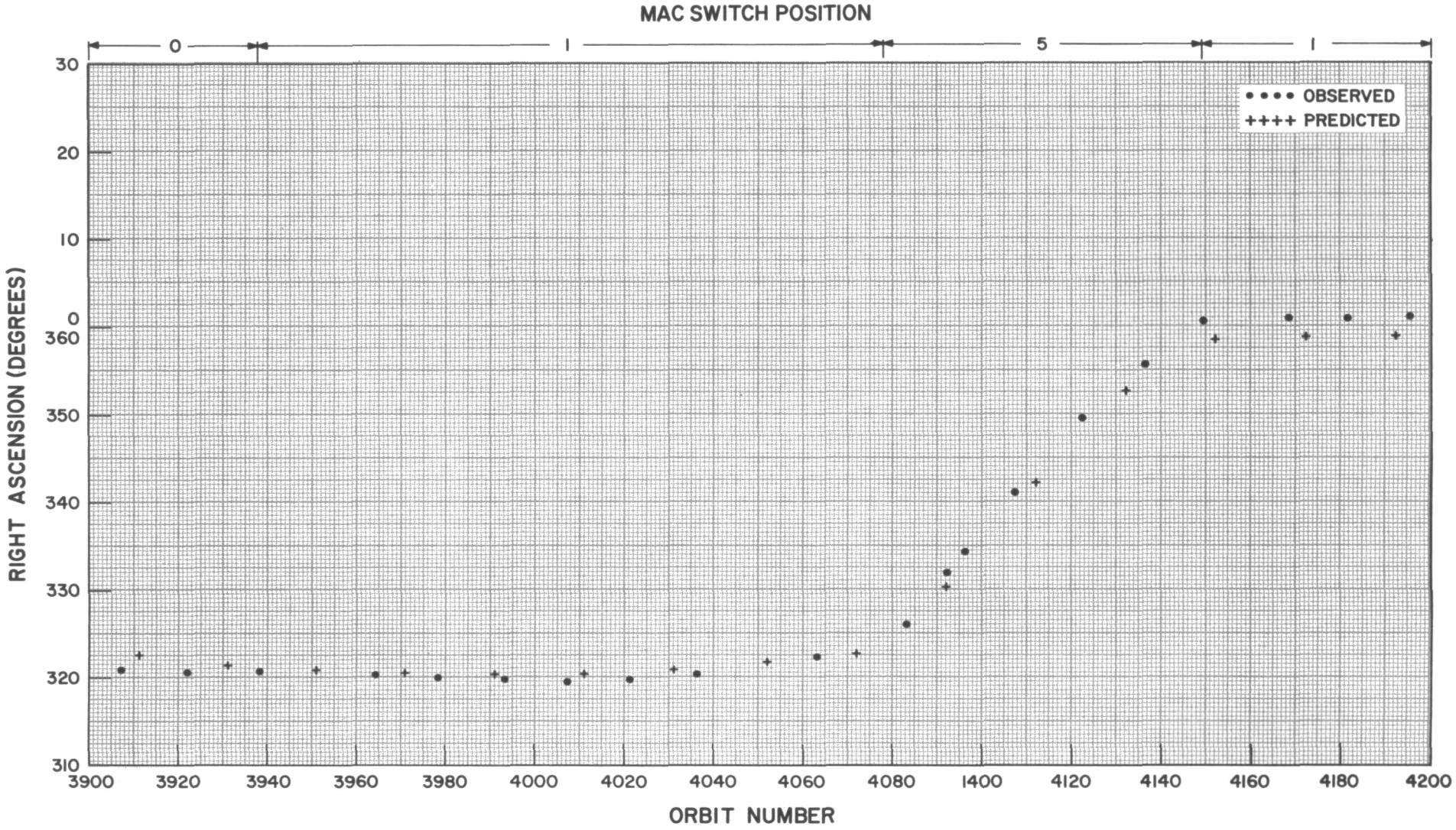

Figure IX-3. Normal Point Right Ascension versus Orbit Number (Sheet 14 of 16)

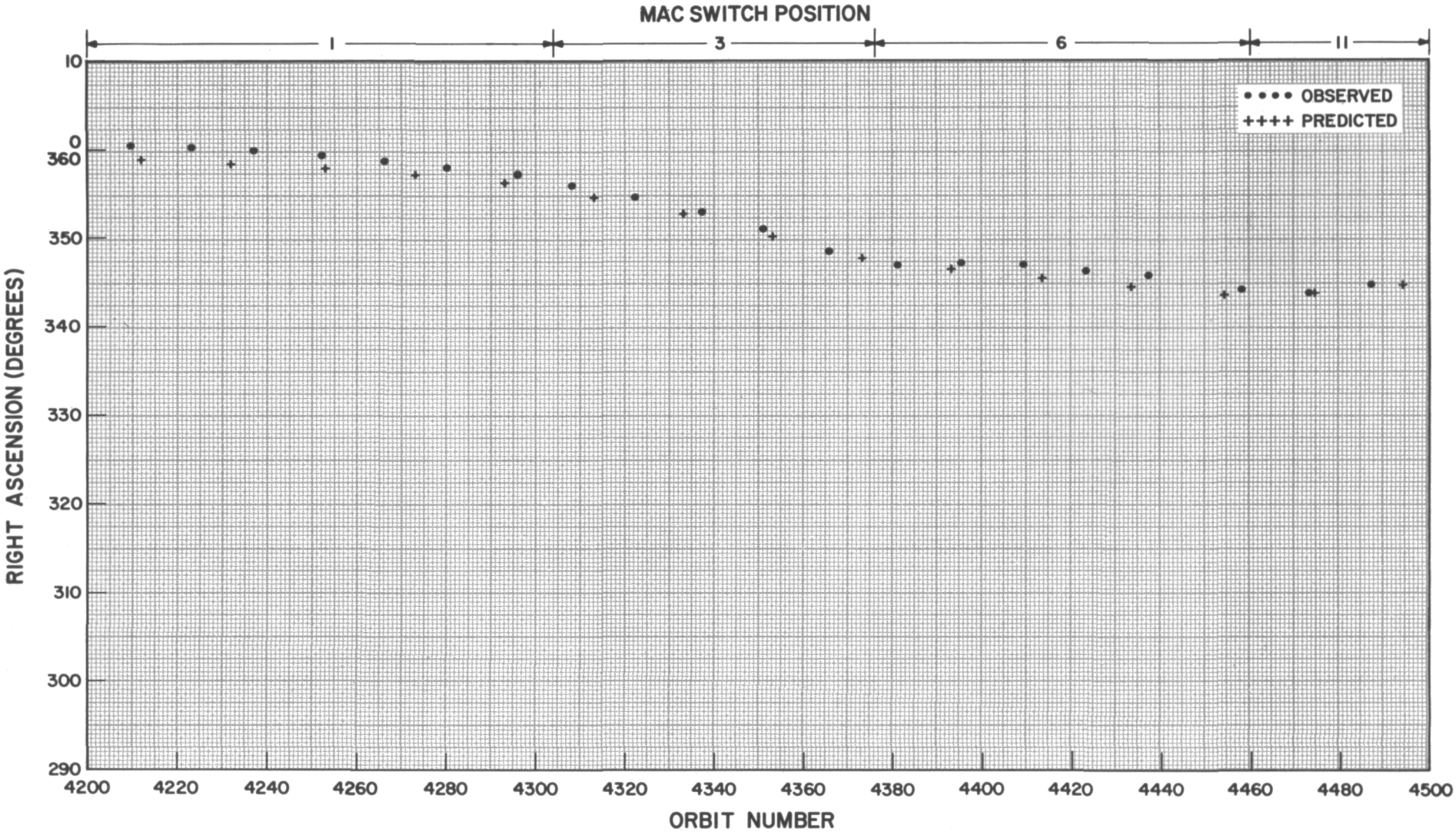

Figure IX-3. Normal Point Right Ascension versus Orbit Number (Sheet 15 of 16)

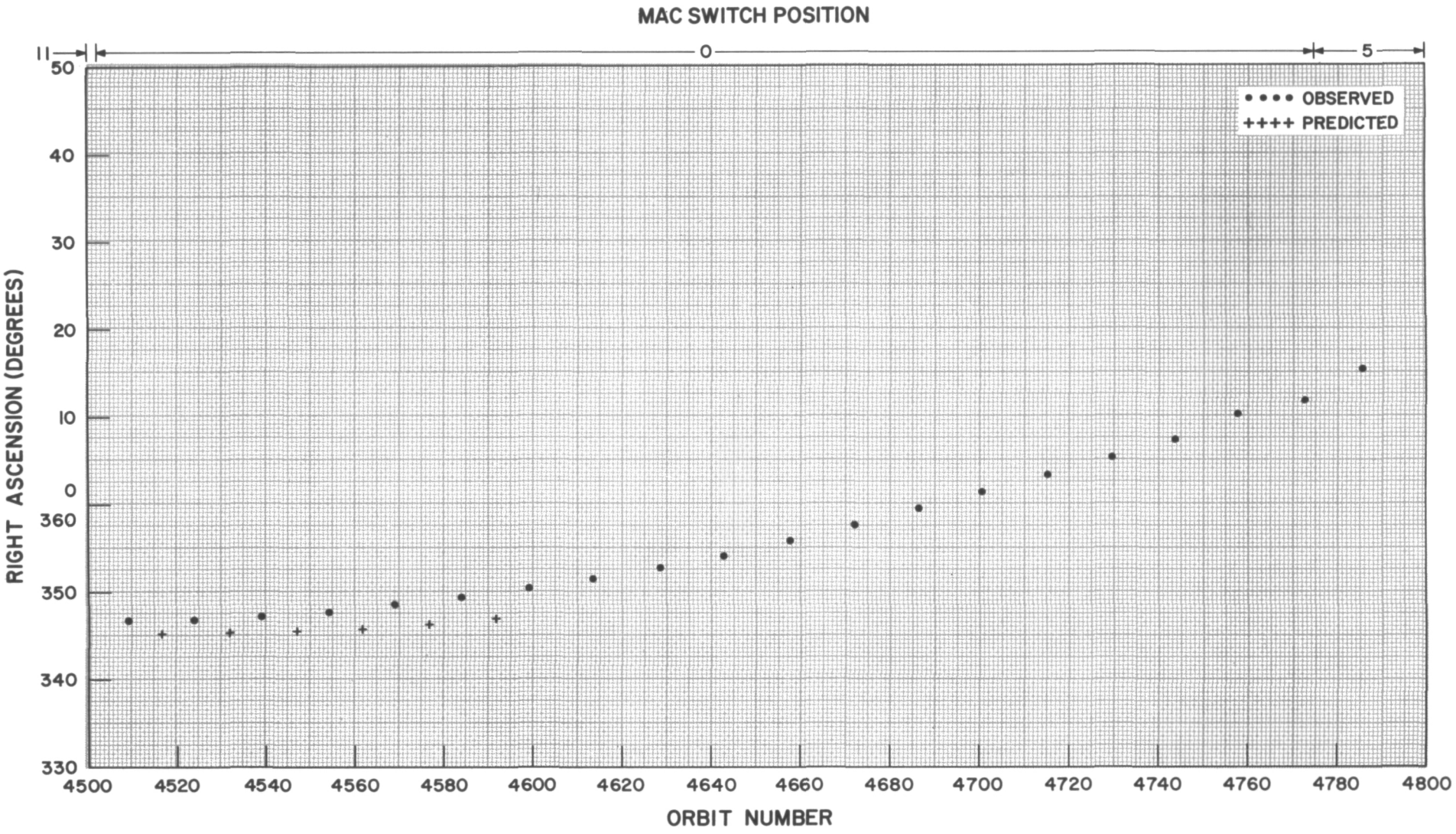

Figure IX-3. Normal Point Right Ascension versus Orbit Number (Sheet 16 of 16)

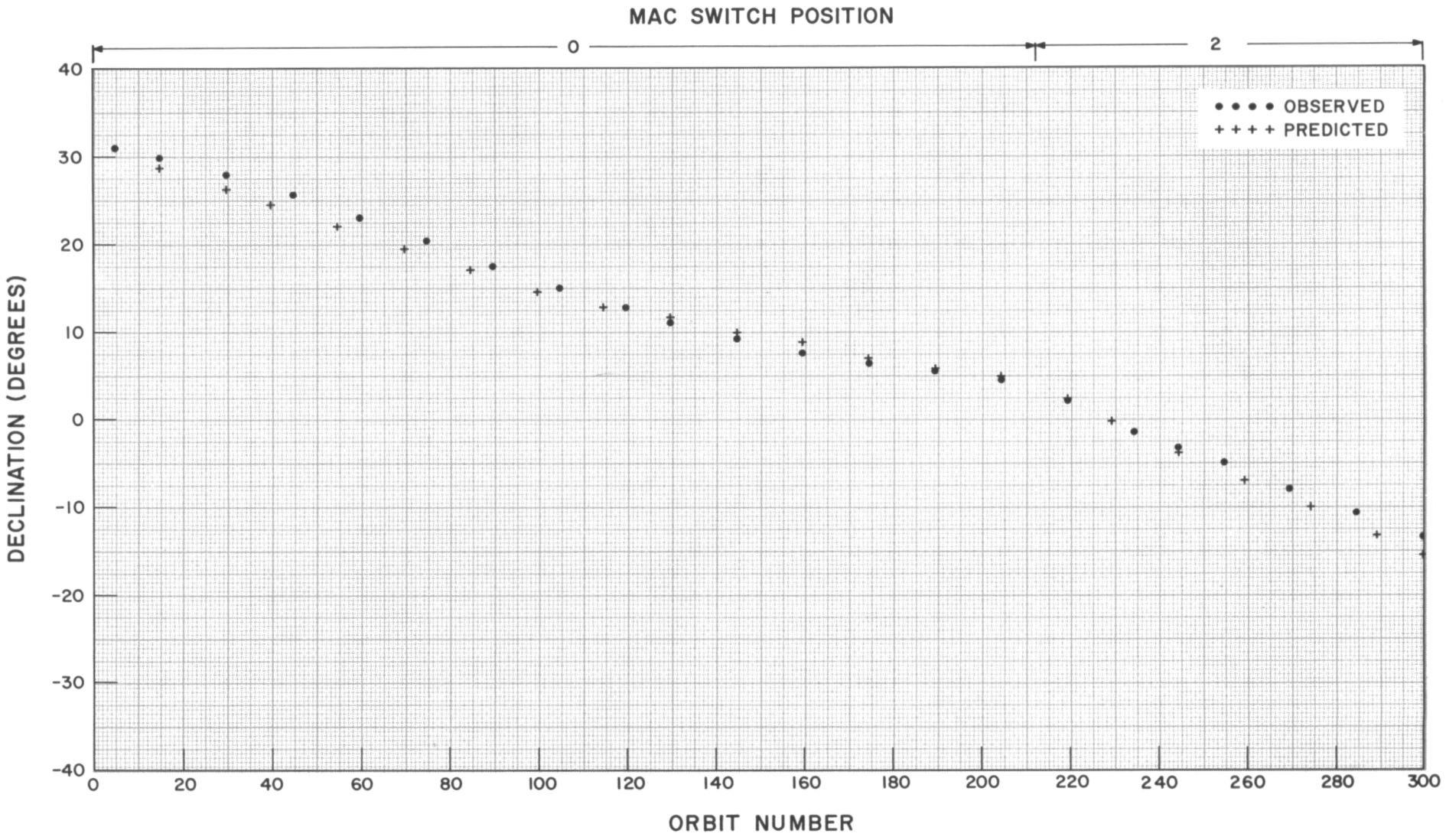

Figure IX-4. Normal Point Declination versus Orbit Number (Sheet 1 of 16)

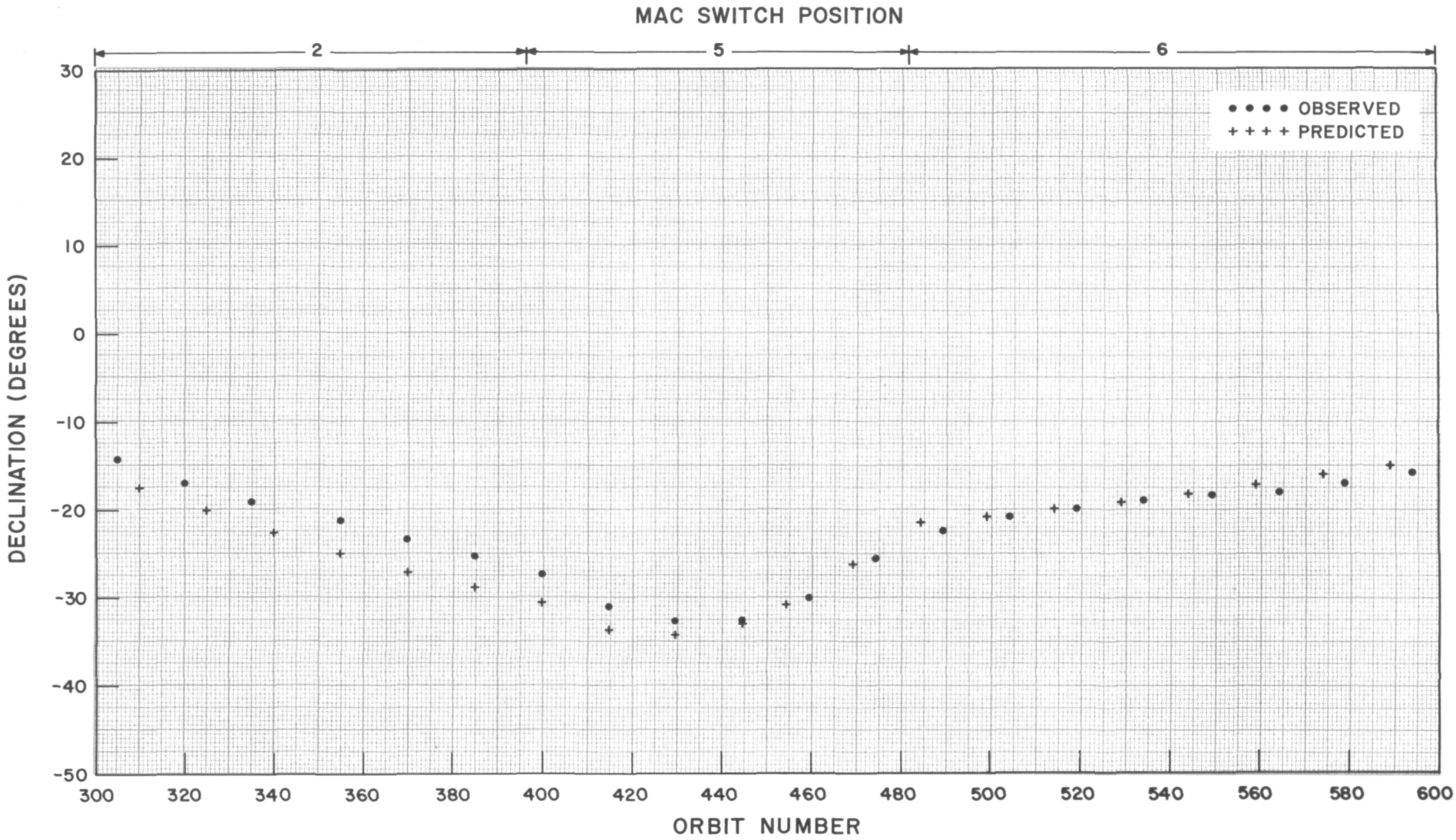

Figure IX-4. Normal Point Declination versus Orbit Number (Sheet 2 of 16)

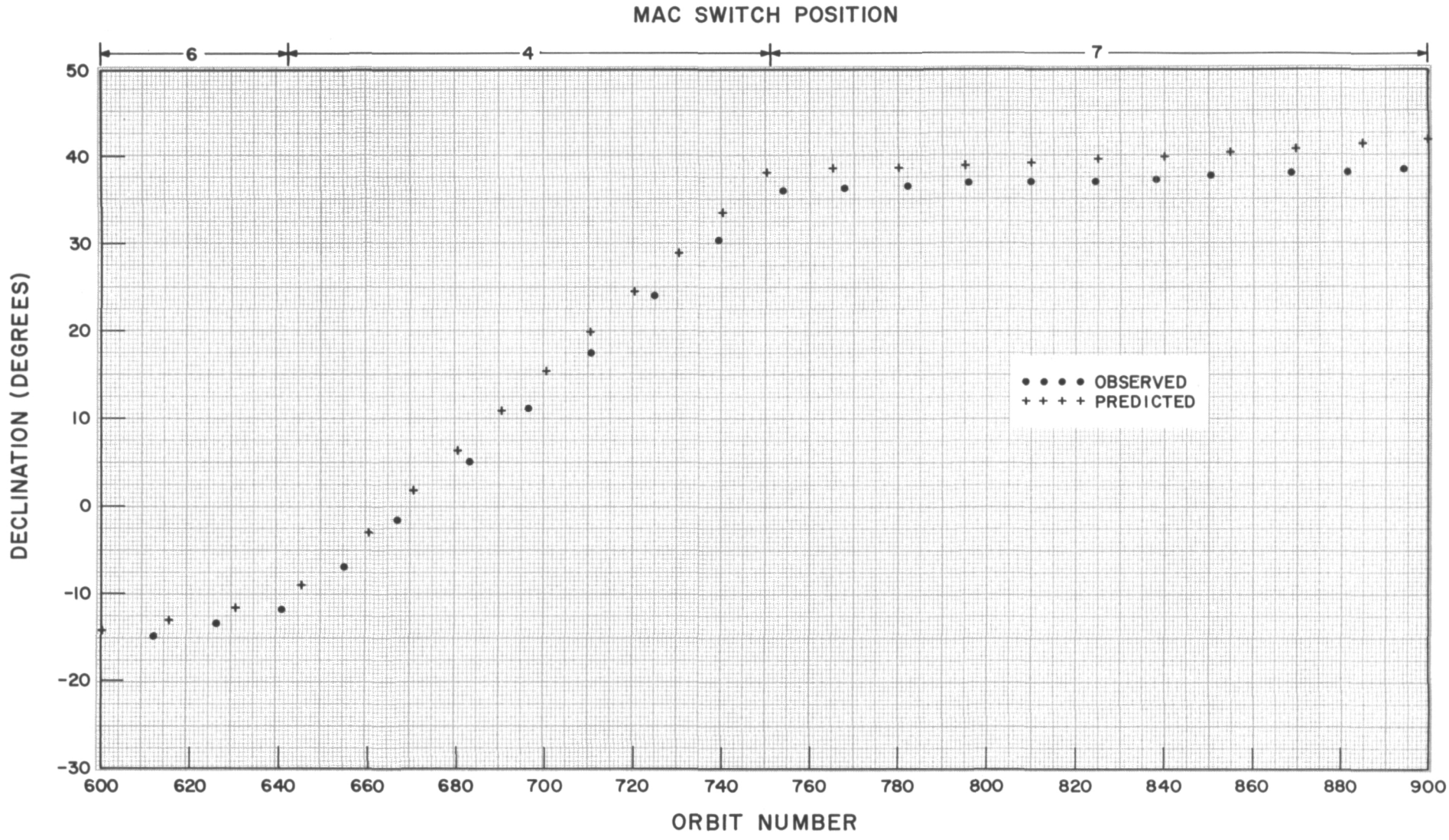

Figure IX-4. Normal Point Declination versus Orbit Number (Sheet 3 of 16)

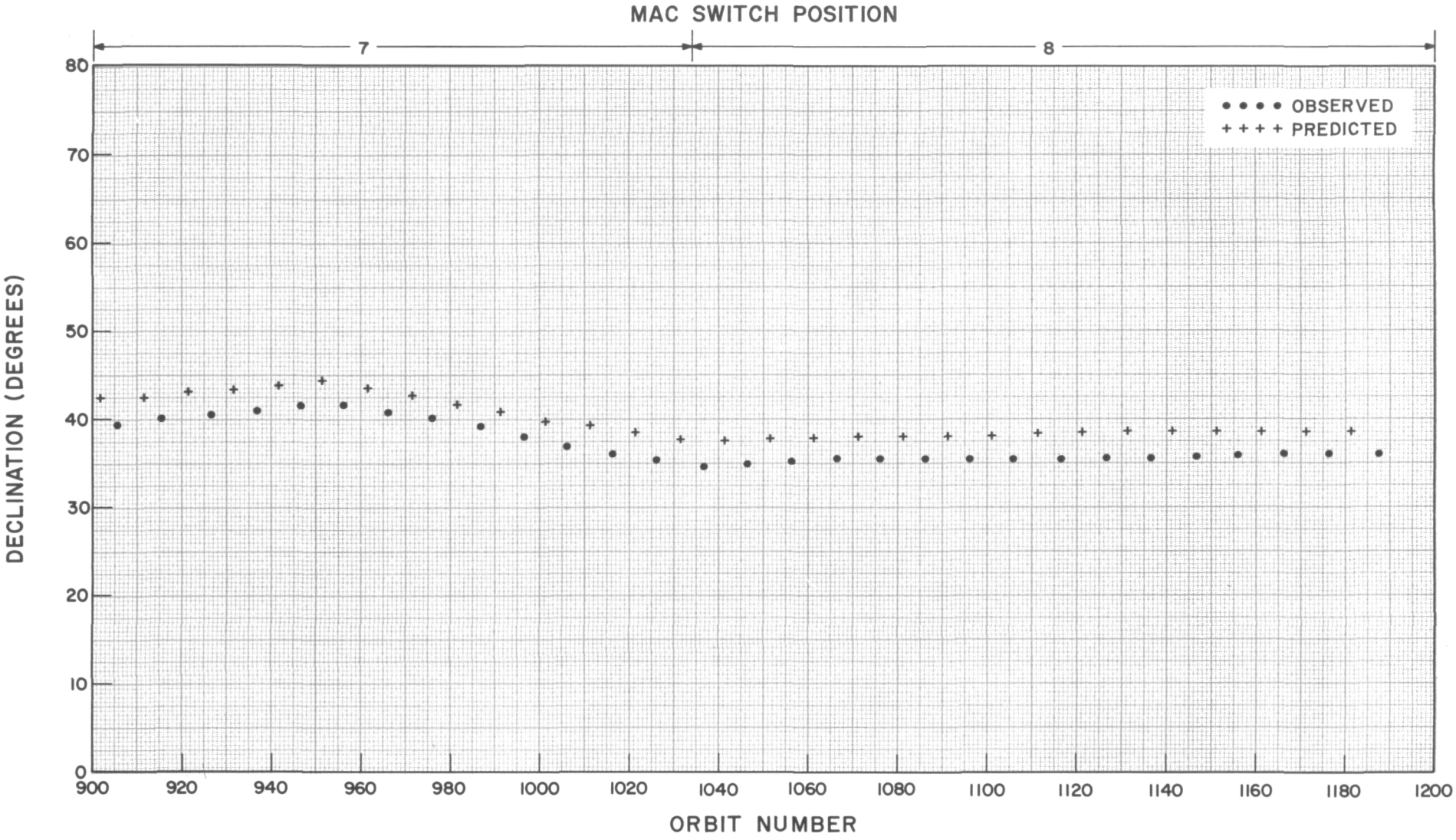

Figure IX-4. Normal Point Declination versus Orbit Number (Sheet 4 of 16)

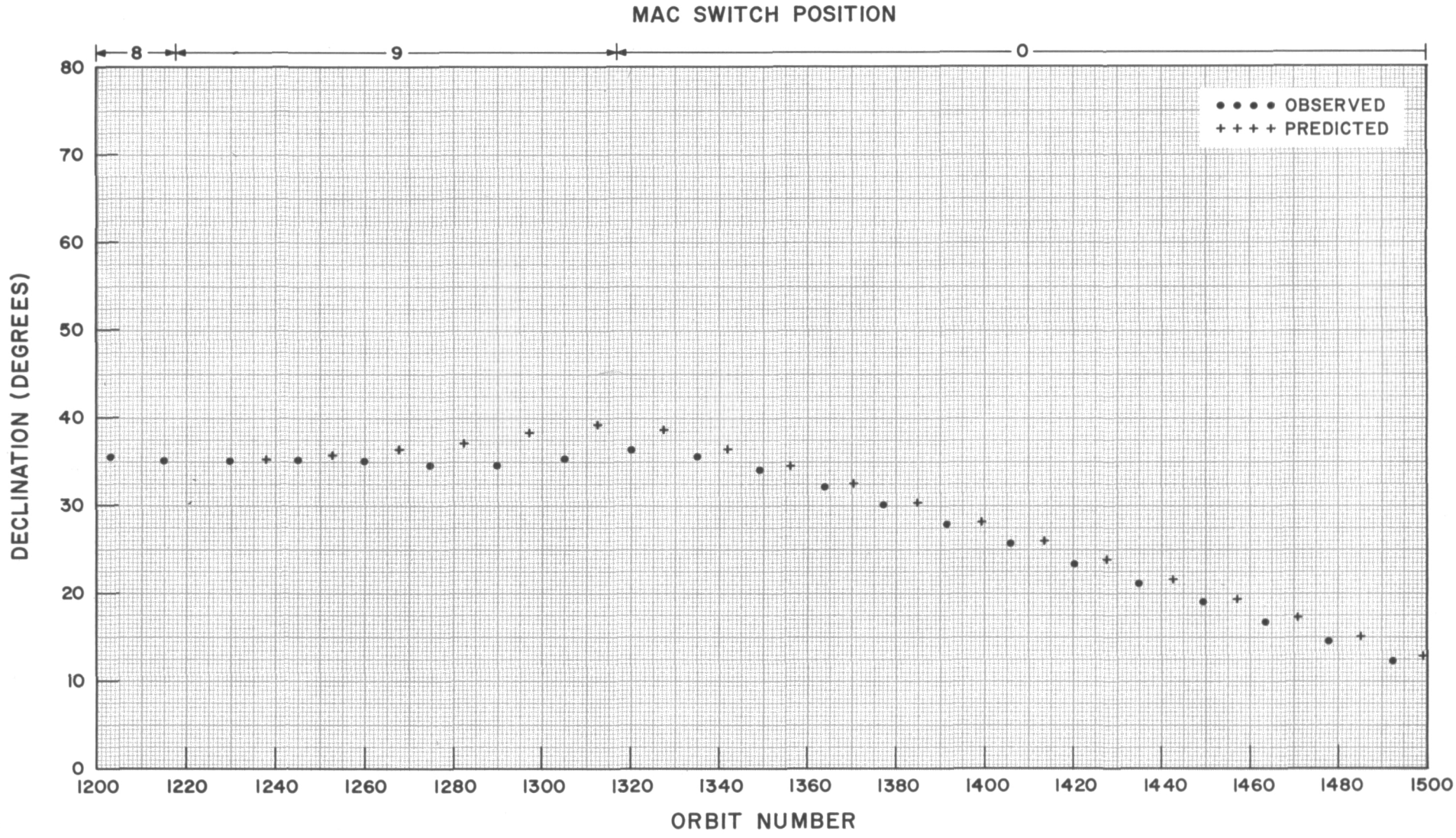

Figure IX-4. Normal Point Declination versus Orbit Number (Sheet 5 of 16)

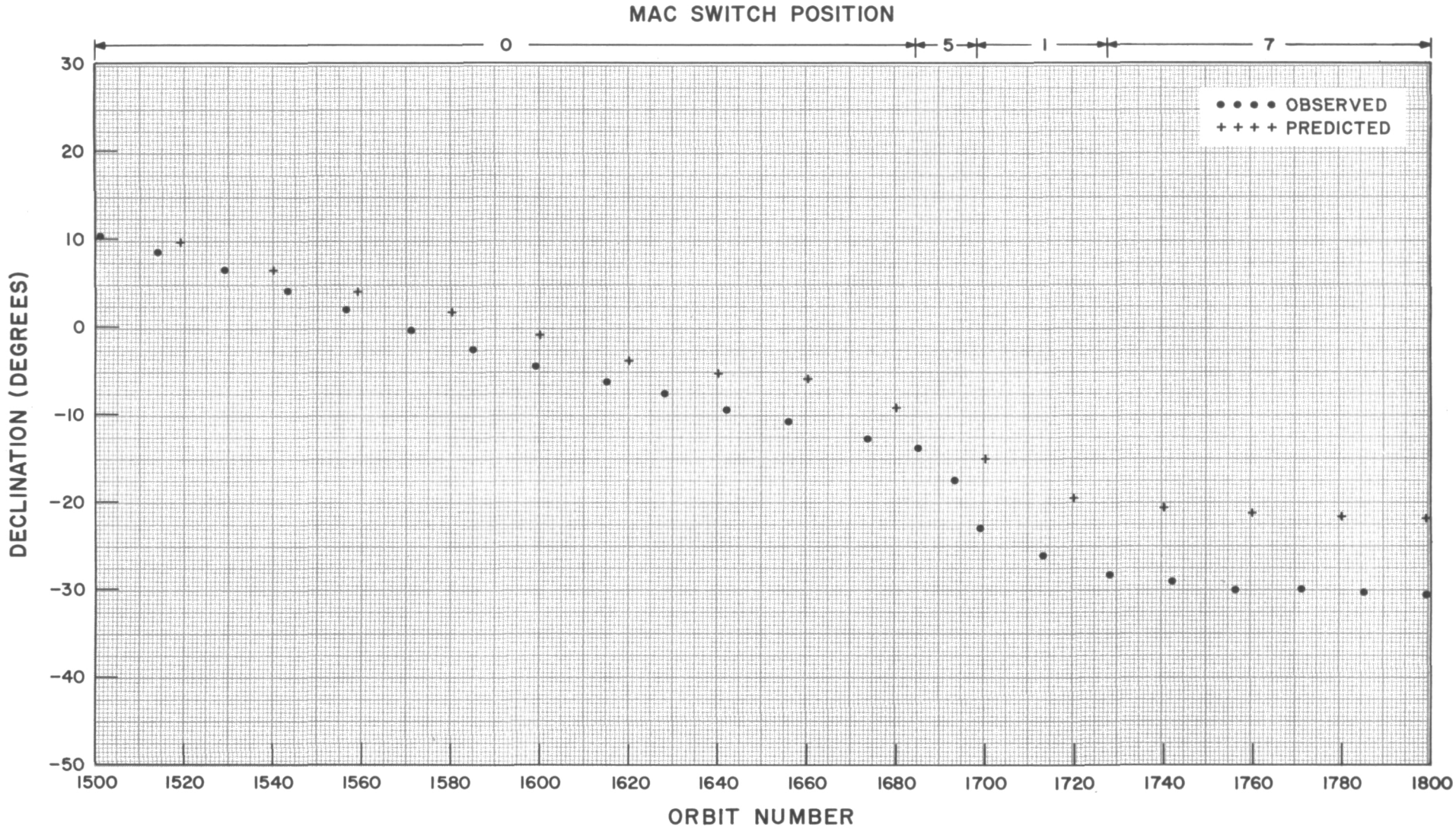

Figure IX-4. Normal Point Declination versus Orbit Number (Sheet 6 of 16)

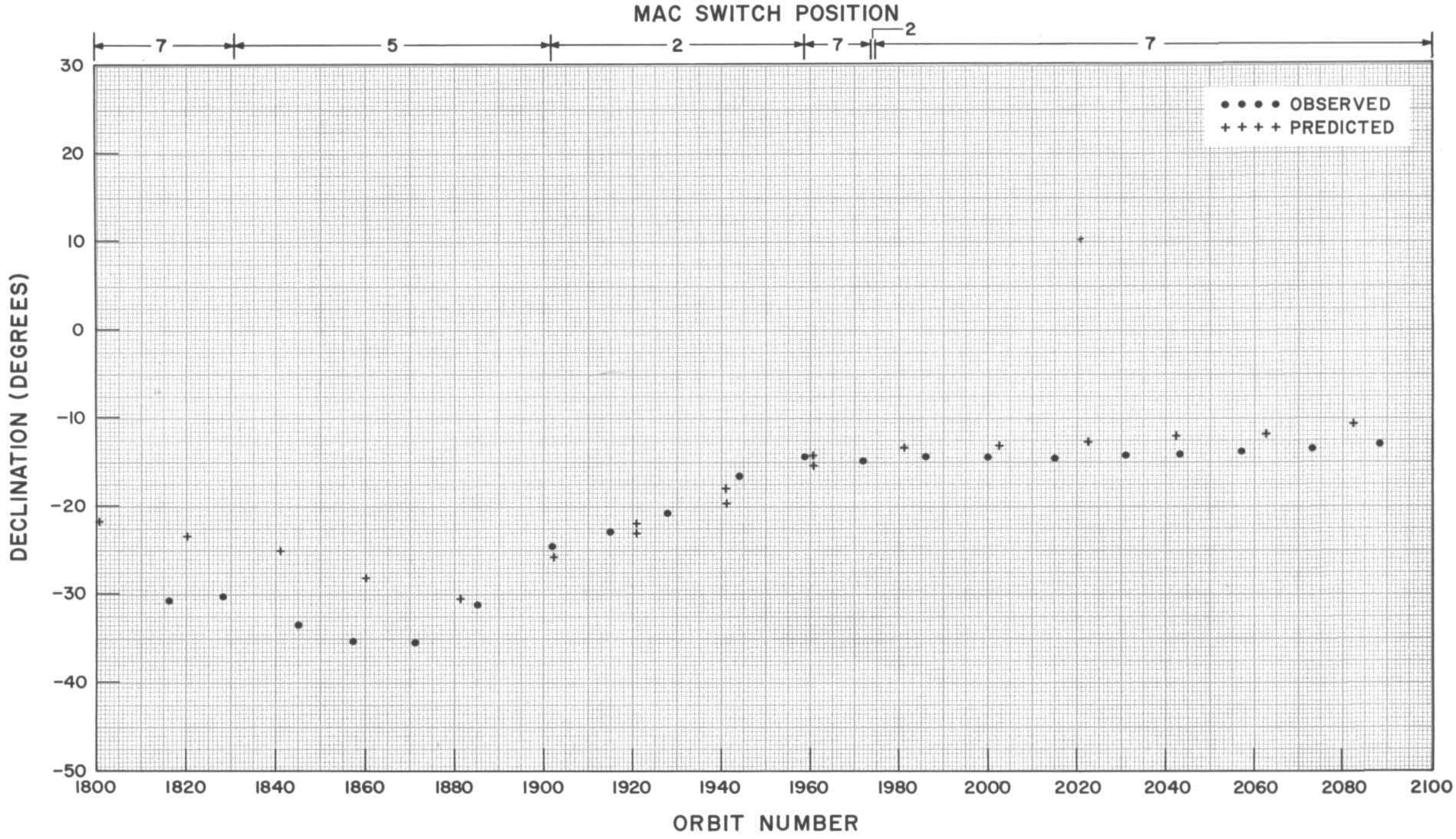

Figure IX-4. Normal Point Declination versus Orbit Number (Sheet 7 of 16)

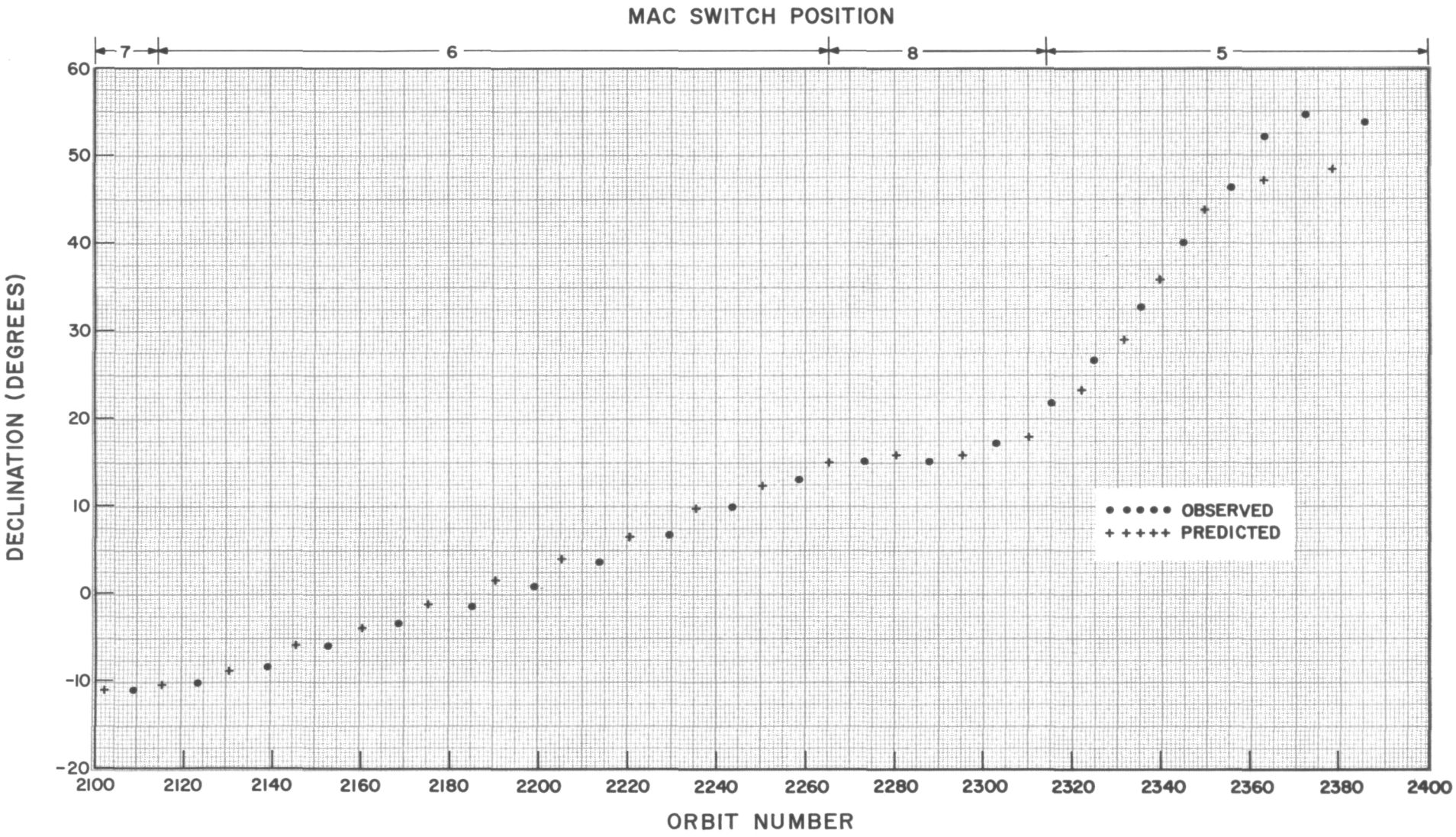

Figure IX-4. Normal Point Declination versus Orbit Number (Sheet 8 of 16)

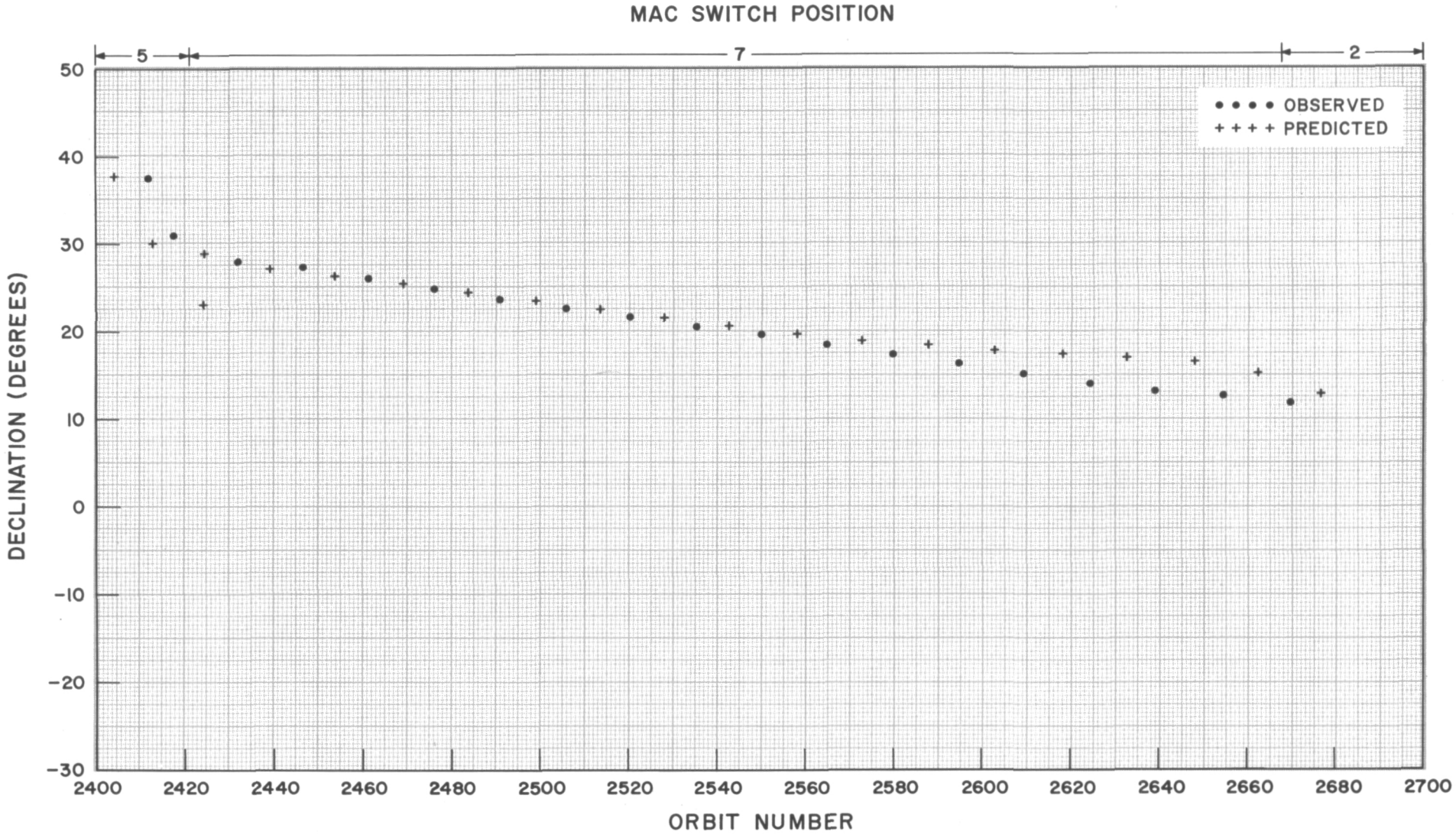

Figure IX-4. Normal Point Declination versus Orbit Number (Sheet 9 of 16)

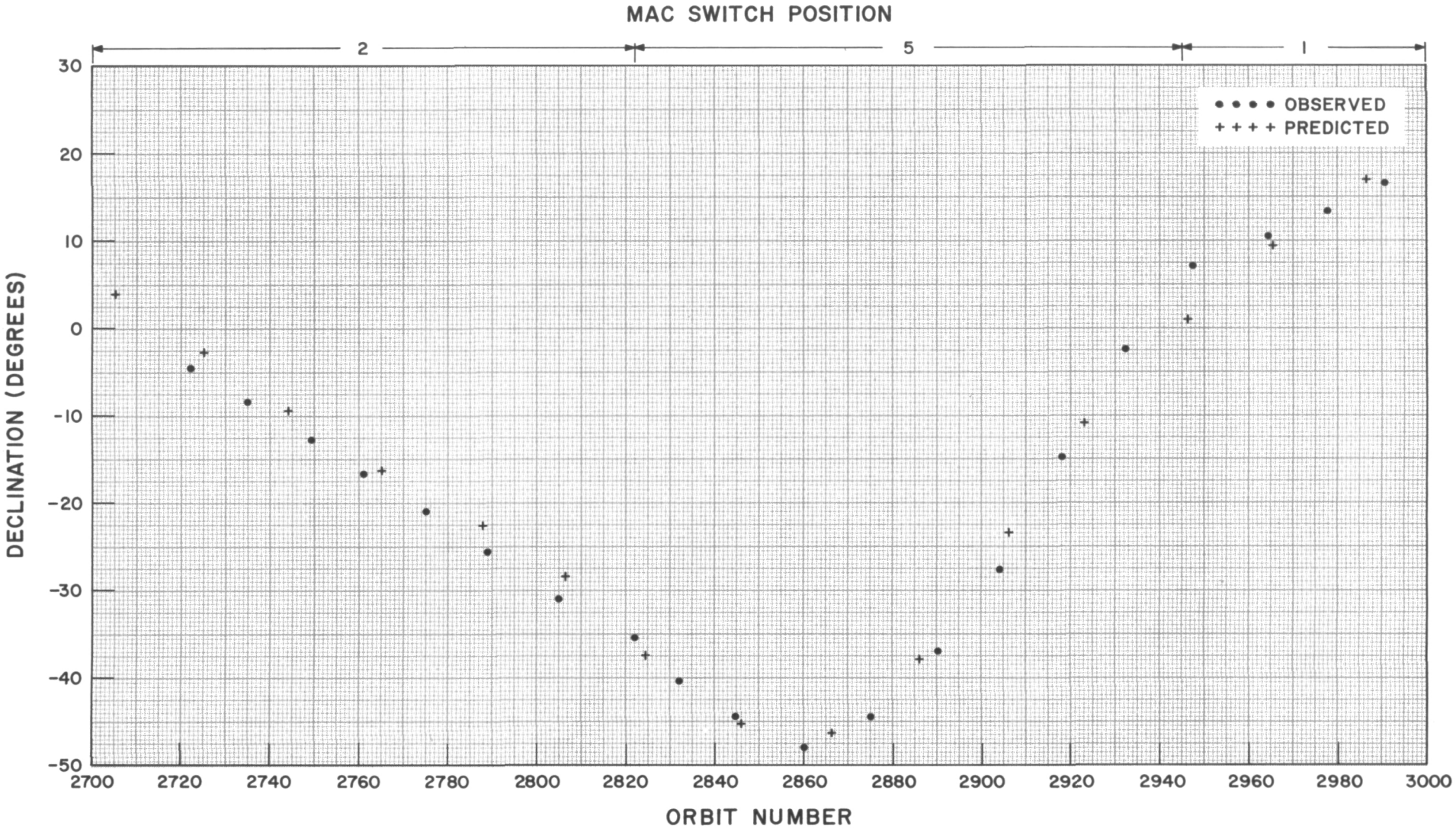

Figure IX-4. Normal Point Declination versus Orbit Number (Sheet 10 of 16)

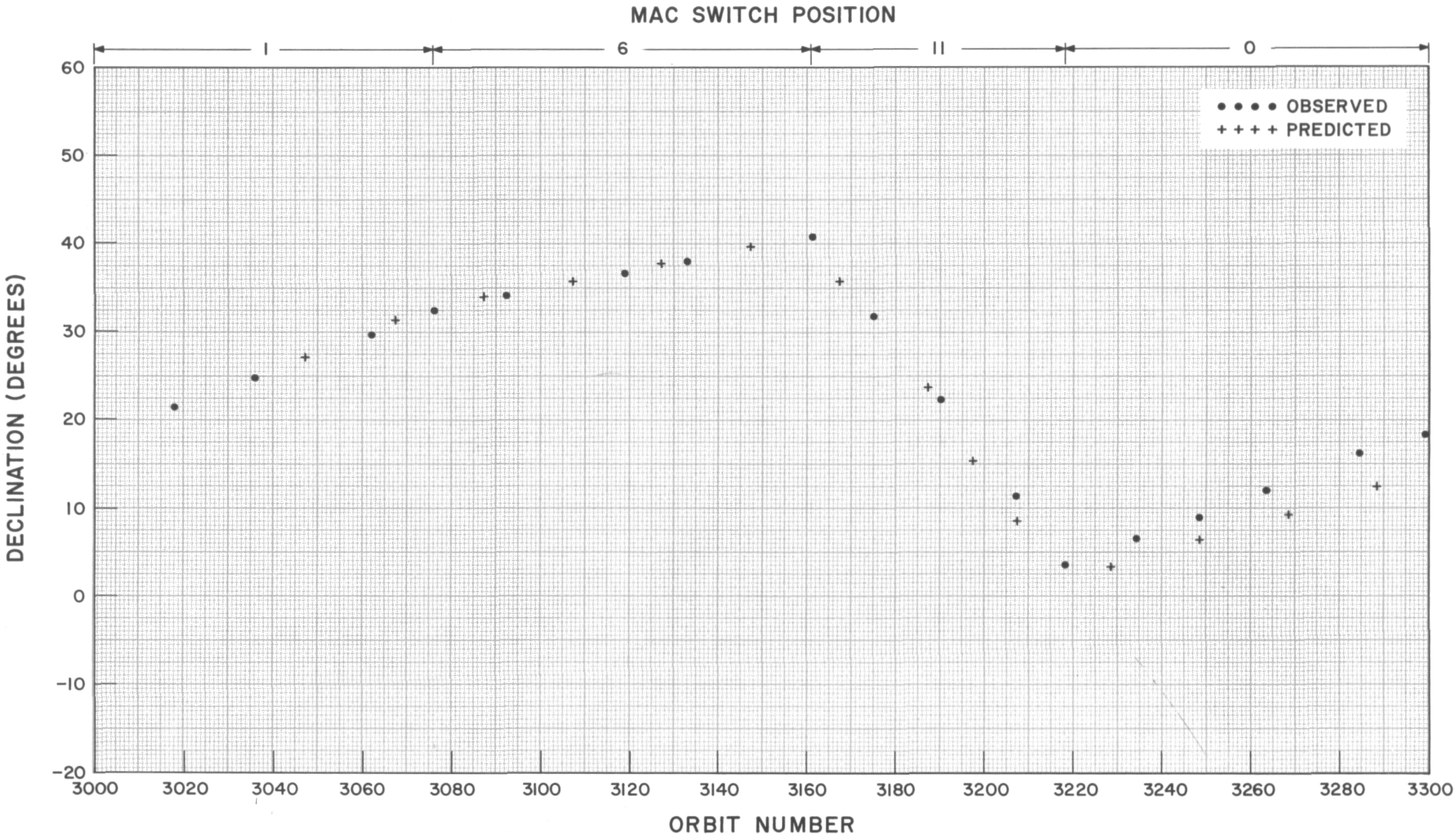

Figure IX-4. Normal Point Declination versus Orbit Number (Sheet 11 of 16)

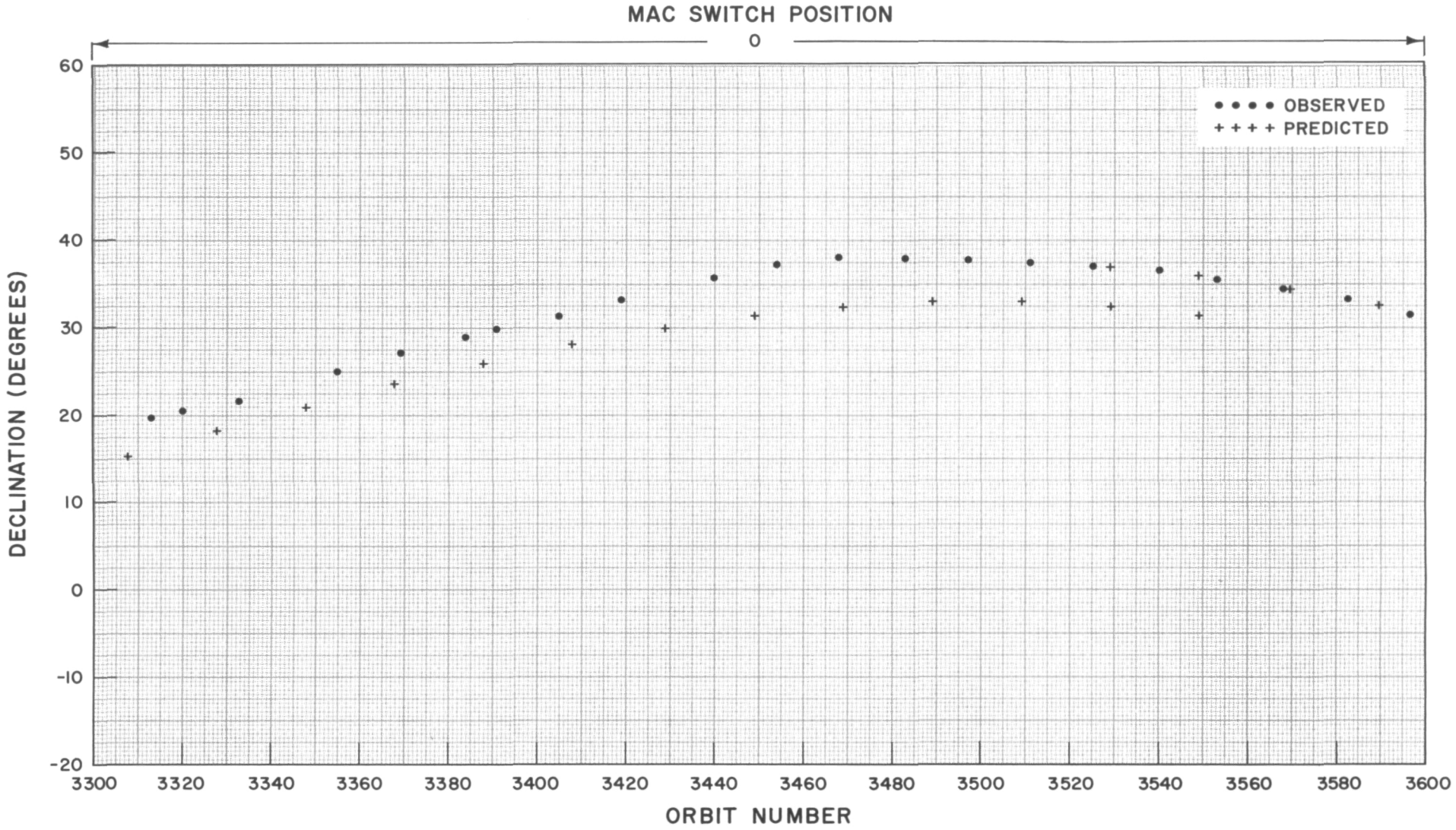

Figure IX-4. Normal Point Declination versus Orbit Number (Sheet 12 of 16)

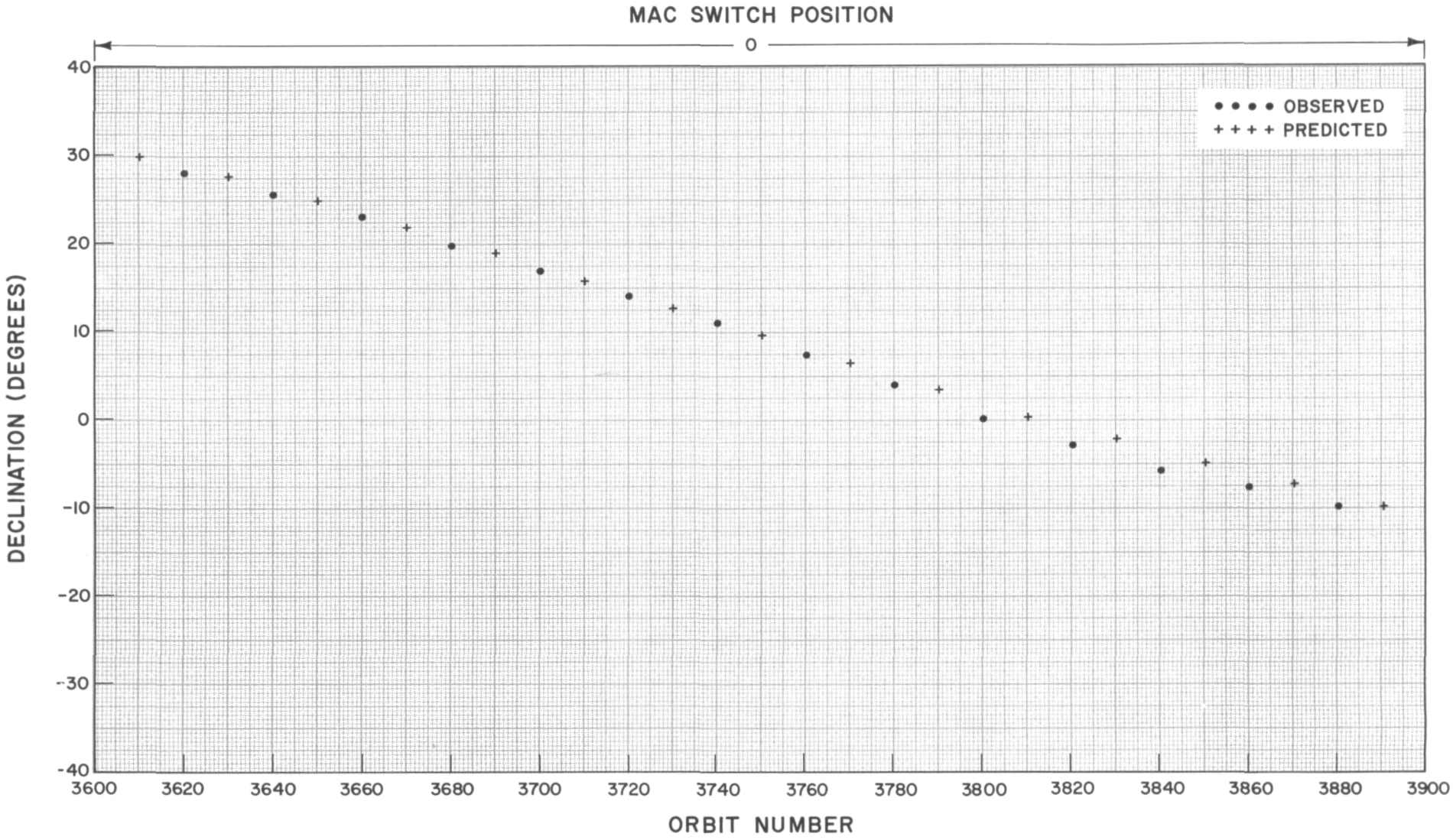

Figure IX-4. Normal Point Declination versus Orbit Number (Sheet 13 of 16)

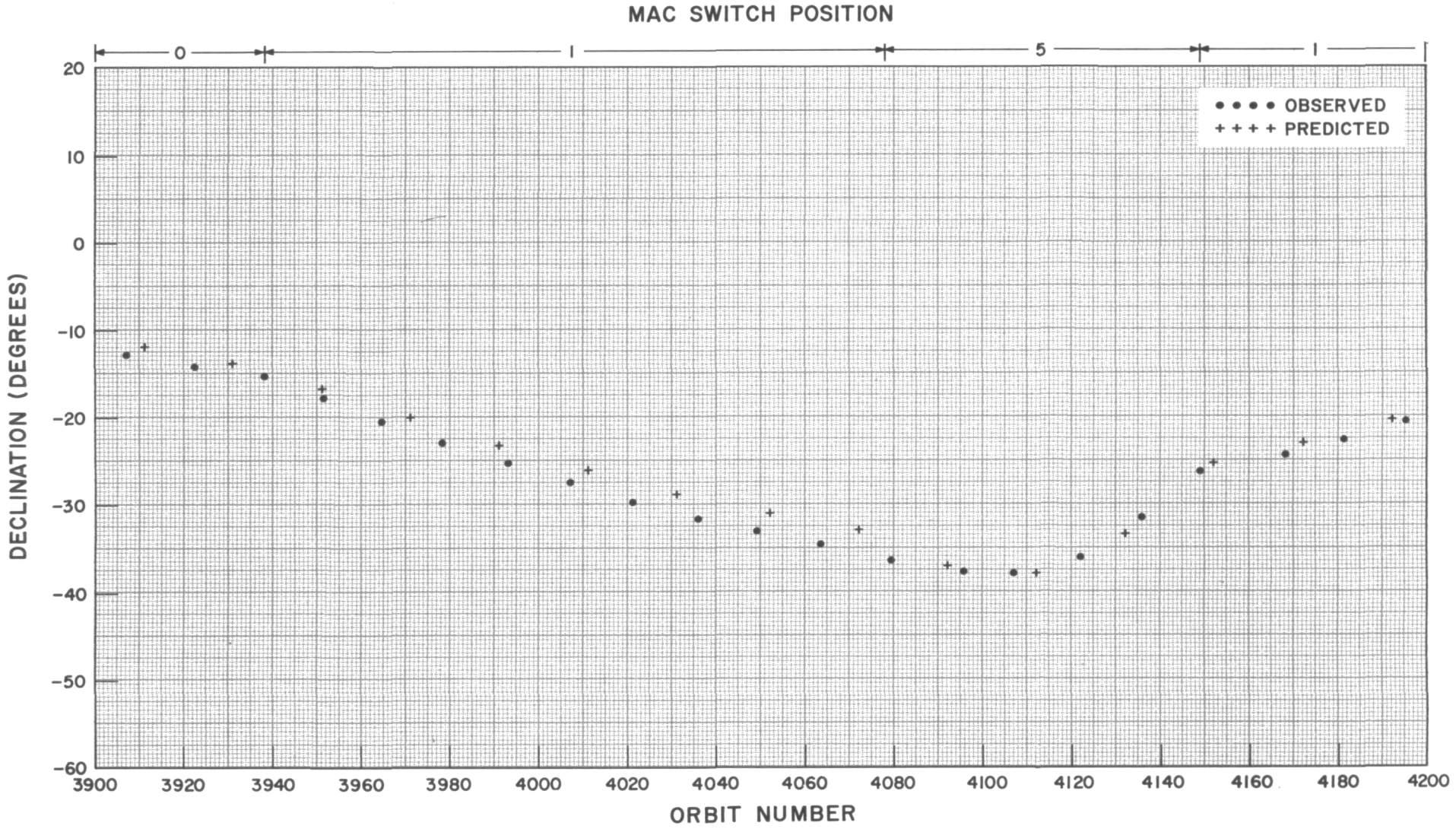

Figure IX-4. Normal Point Declination versus Orbit Number (Sheet 14 of 16)

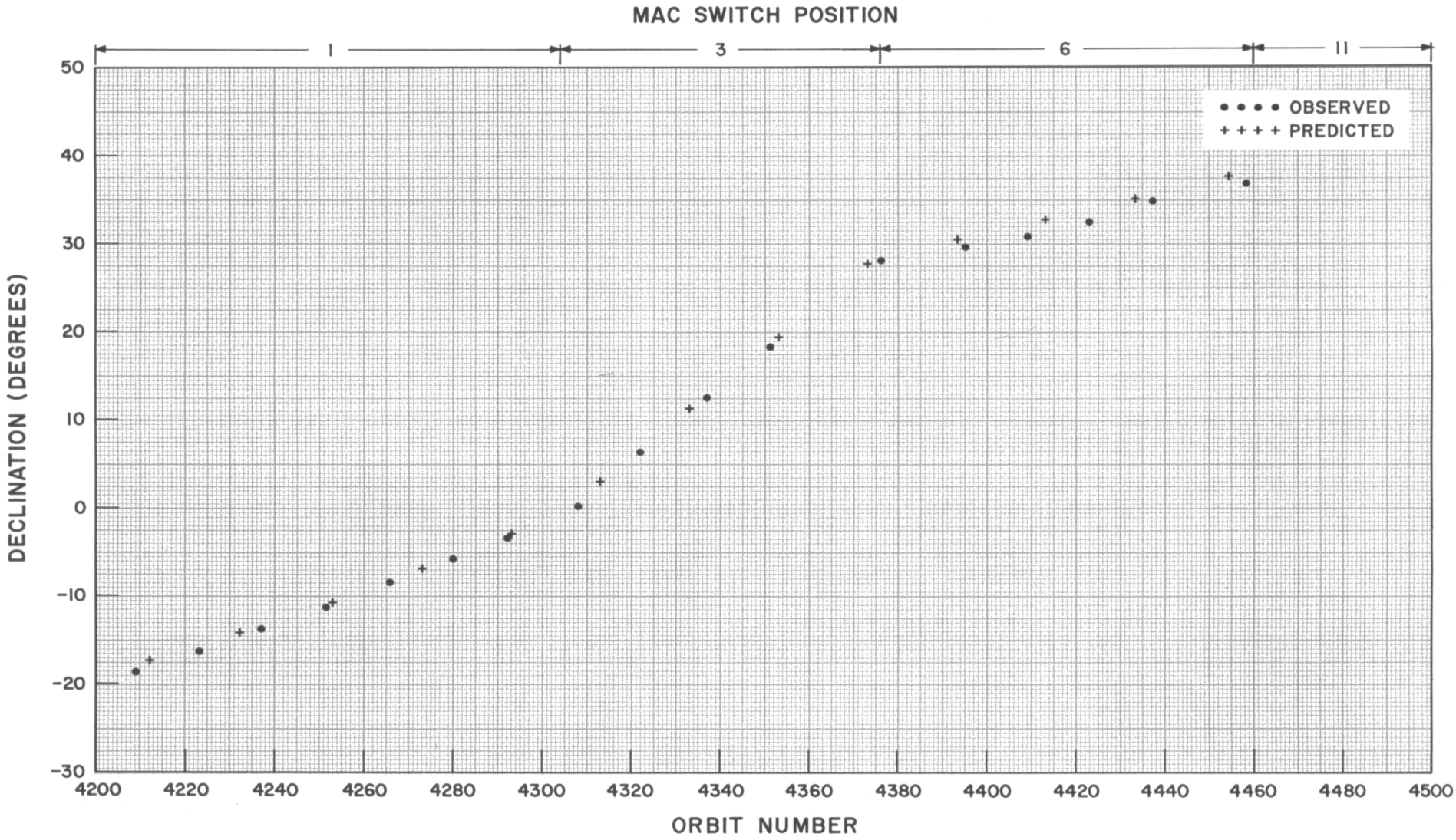

Figure IX-4. Normal Point Declination versus Orbit Number (Sheet 15 of 16)

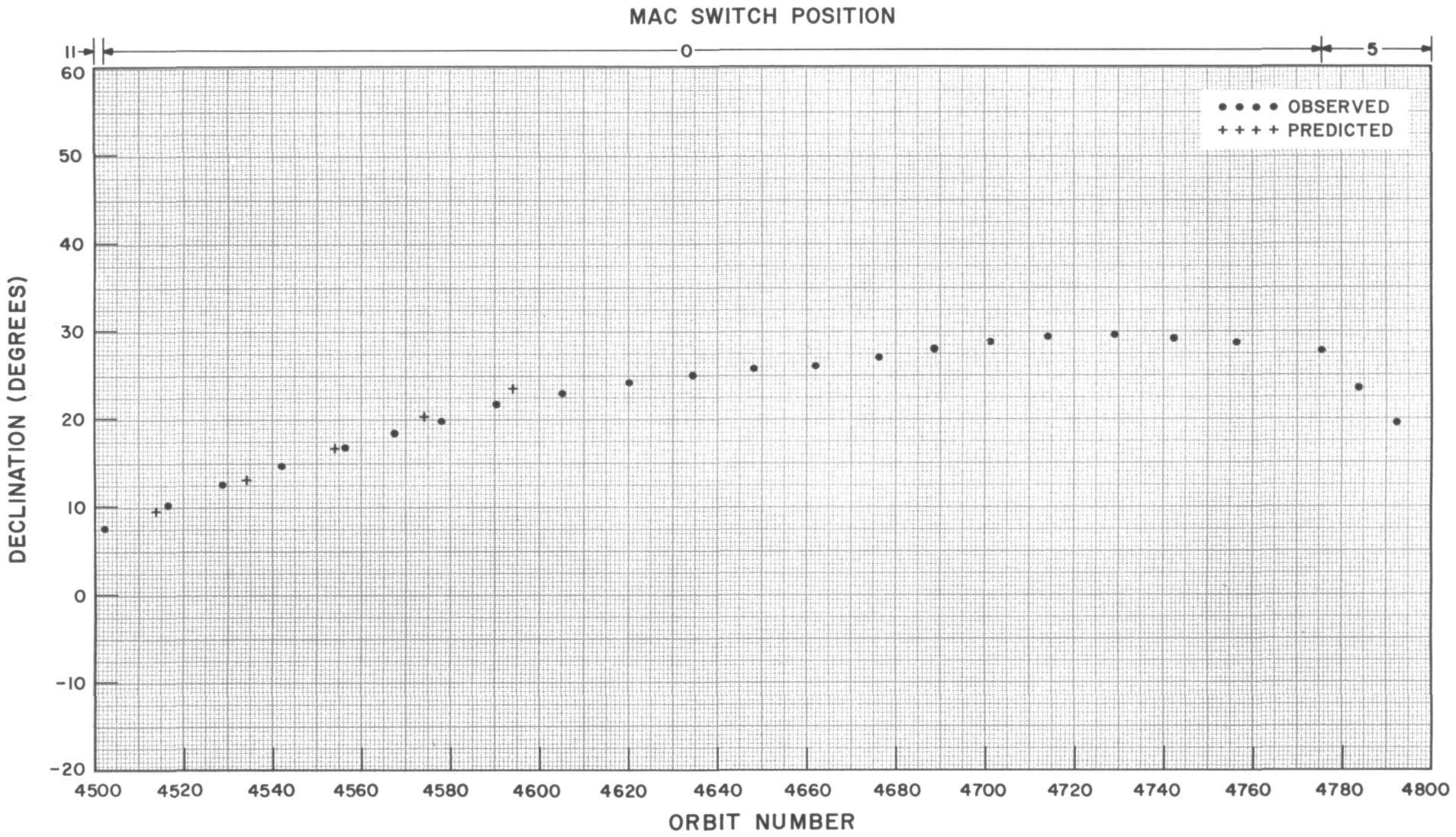

Figure IX-4. Normal Point Declination versus Orbit Number (Sheet 16 of 16)

X. ANTENNA SUBSYSTEMS

A. FUNCTION

1. General

The satellite antenna subsystem provided the means for the reception of command signals from the CDA ground stations and for the simultaneous radiation of energy from the four separate transmitters (two beacon, one IR, and either one of two TV). The subsystem also provided for coupling and matching of the receivers and transmitters to the antennas and for isolating the four active transmitters and the two command receivers.

The CDA ground station antenna subsystem provided for the reception of the TV, IR, and beacon signals from the satellite and for the transmission of command signals to the satellite.

The antenna subsystems were basically the same as those used for TIROS IV.

2. Satellite Antenna Subsystem

The command receivers of the satellite utilized a simple dipole receiving antenna. The beacon, TV, and IR transmitters shared two crossed-dipole antennas (two frequencies) by means of a coupling and matching network which coupled the four antenna segments to achieve a circularly polarized output. An RF relay switching network was employed to connect the output from one of the TV transmitters to the matching and coupling network.

The matching and coupling network for the transmitting antennas provided:

(1) coupling of at least two transmitters in each frequency band to the radiating elements with a minimum of feedback between transmitters,

(2) sufficient isolation to prevent interaction between transmitters operating in different frequency bands, and

(3) division of energy from each transmitter into four branches so that the currents were of equal magnitude in all branches and were properly phased to produce circular polarization.

3. Ground Station Antennas

Signals from the TIROS V satellite were received by a 60-foot parabolic antenna at the PMR ground station. The Wallops Island ground station was equipped with two antennas. A General Bronze swept-volume efficiency antenna, having a gain of 29 db and similar in design to the antenna at the AED station, was used to receive the TV and IR signals in the 235-Mc region; a crossed-helix antenna was used for receiving the 136-Mc beacon signals. The command antenna at Wallops Island was mounted on the same gimbling mount as the 136-Mc antenna. At the PMR station the command antenna was mounted on the upper rim of the 60-foot antenna. The antennas at both stations were capable of manual and automatic tracking of the satellite.

B. PERFORMANCE

Performance of the satellite antennas in all frequency ranges was normal in every respect throughout the operational life of the satellite. Satisfactory signal strengths from the satellite transmitters were reported by both CDA stations and by the AED back-up station indicating that performance of the transmitting antennas and the antenna matching and coupling network was normal. The consistently good response of the satellite to ground commands gave evidence of satisfactory performance of the command receiving antenna.

Since no difficulties were encountered, no detailed evaluations of the satellite antennas were conducted. However, received signal levels of the TV transmissions were carefully monitored to verify that the modified sensor support-arm array for the omni-directional IR experiment had eliminated the simultaneous nulls in the TV transmitting beam patterns which had been observed on the TIROS III and IV satellites. The background of this problem and the studies leading to the modification are reported in detail in the TIROS V final engineering report.

Pattern measurements of the TIROS V antennas made on the RCA antenna propagation range, indicated that the support-arm modification had satisfactorily restored the original beam patterns that existed before the addition of the omni-directional IR experiment to the TIROS satellite. In order to confirm that these measurements made on the antenna range were valid for the space environment, recordings were made of the AGC voltages, which are indicative of signal strengths in the two television diversity receiving channels. Ephemeris data provided by NASA was used to determine the real times during representative orbits when the satellite look angle passed through 150 degrees, the angle at which the simultaneous nulls had occurred. The AGC data corresponding with these times were then studied to determine the nature of the signal strengths while the spacecraft was in the critical angular relation to the ground station.

Three passes during which the spacecraft went through the critical angle took place on orbits 113, 142 and 156. Copies of pertinent portions of the AGC recordings are included here, as Figures X-1 through X-3, with a plot of the look angle-versus-real time added in true time relation to the signal strength recordings. Passes during which the critical look angle occurred at low elevation angles were not considered in the study because ground reflections could render the findings inconclusive.

It is plainly evident from the graphical presentations that no simultaneous fades occurred during any of the periods observed, and that the out-of-phase relation between the minima of the vertical and horizontal components follows the same characteristic radiation pattern produced by the TIROS spacecraft that antedated the IR experiment. The results of this study have proved beyond any doubt that the modification of the sensors of the IR experiment has solved the fading problem; moreover these results have proved that the antenna-range pattern measurements are indeed accurate and valid for use in predicting actual operation in space.

The ground station antennas also performed satisfactorily. Some difficulties were encountered with malfunctions of the antenna drive systems and with adverse weather conditions, although never for extended periods. These difficulties are discussed in Section XIII of this report.

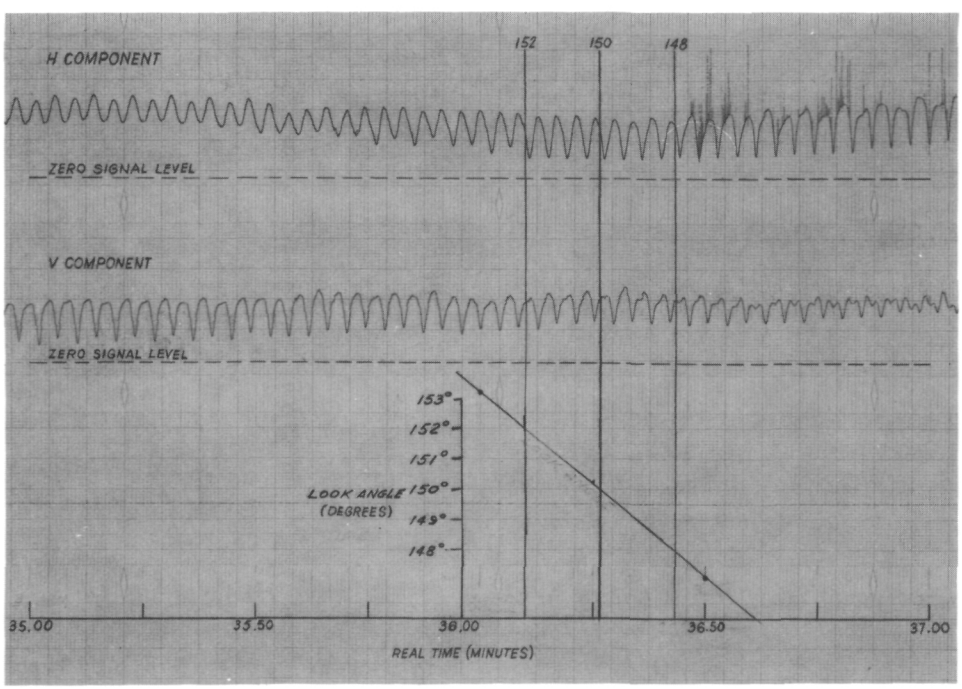

Figure X-1. TIROS V TV Receiver AGC Recordings, Showing Time of Critical Look Angle (150 degrees) on Orbit 113 (June 27, 1962)

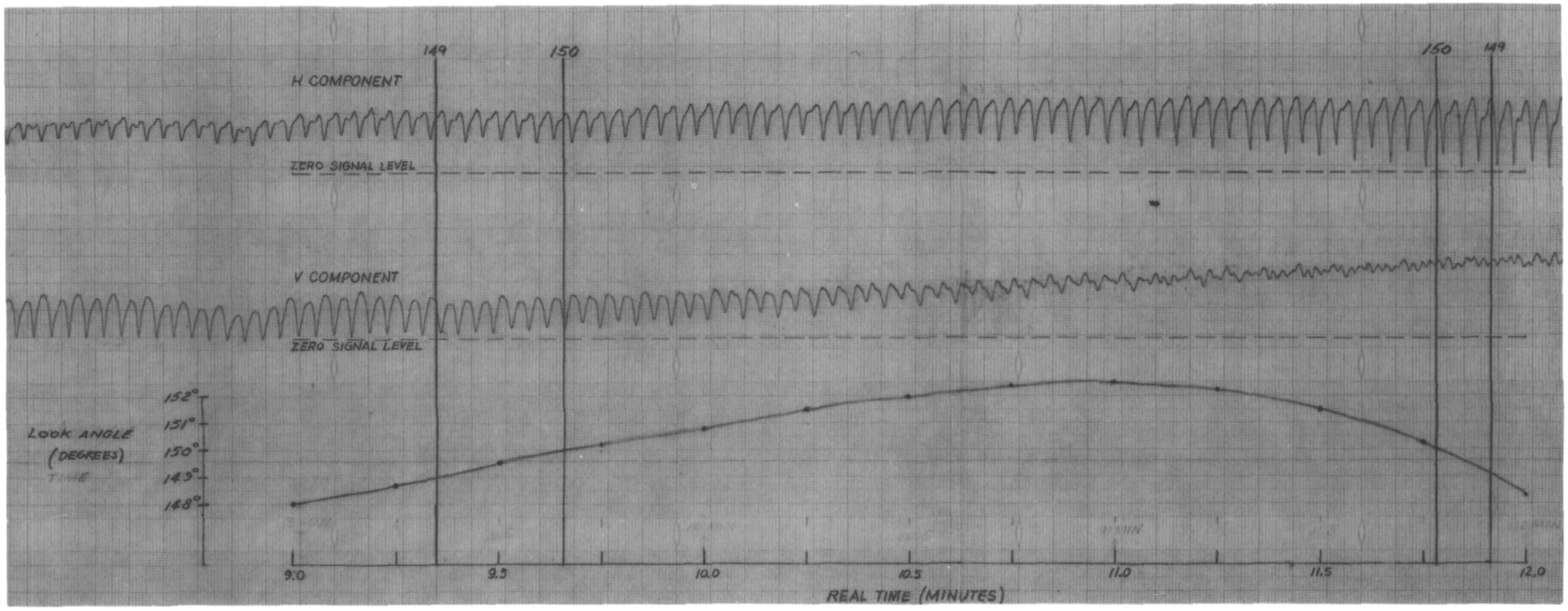

Figure X-2. TIROS V TV Receiver AGC Recordings, Showing Time of Critical Look Angle (150 degrees) on Orbit 142 (June 29, 1962)

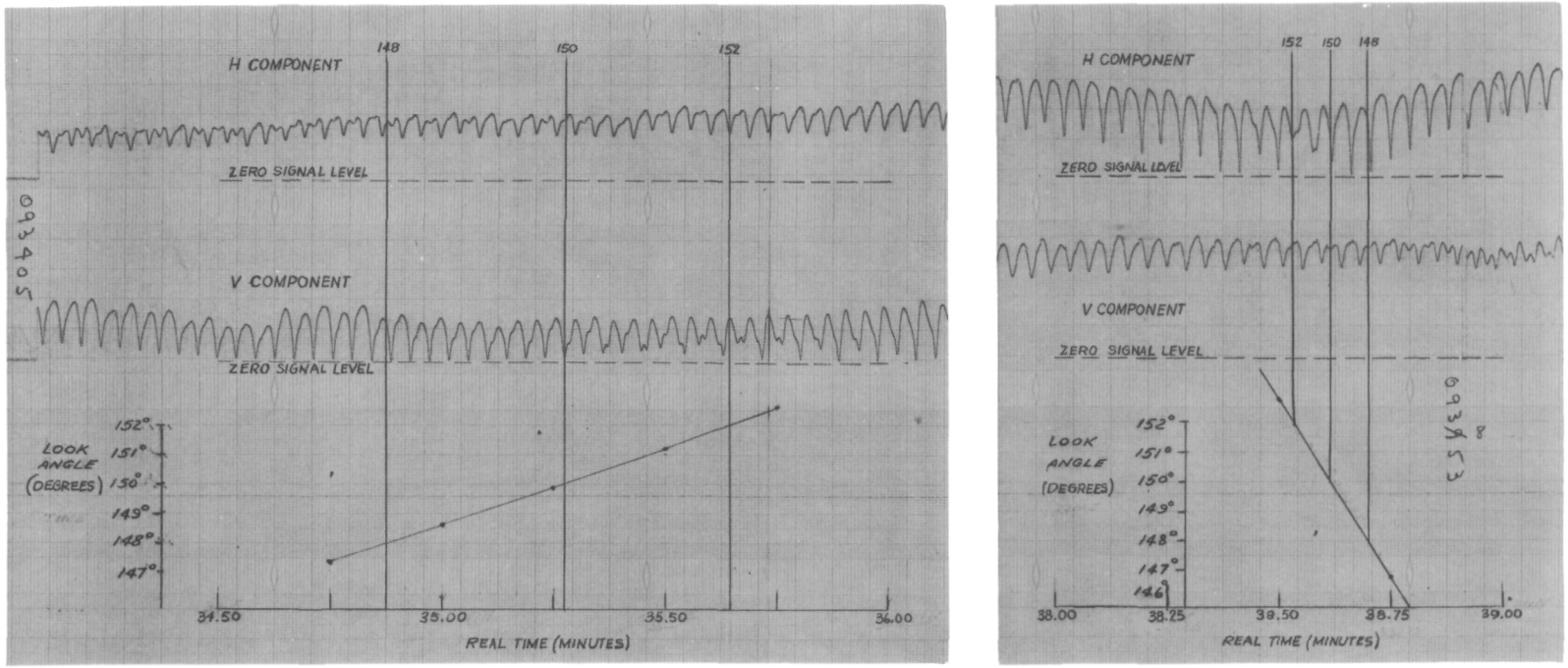

Figure X-3. TIROS V TV Receiver AGC Recordings, Showing Time of Critical Look Angle (150 degrees) on Orbit 156 (June 30, 1962)

XI. ELECTRICAL POWER SUPPLY SUBSYSTEM

A. FUNCTION

The electrical power for all of the requirements of the TIROS V satellite was supplied by a solar-energy converter and a group of 63 nickel-cadmium storage batteries. The solar-energy converter consisted basically of an array of 9120 silicon solar cells, mounted on the top and sides of the satellite structure. During orbital day, when the solar cells were illuminated, the output of the array was used as the satellite's primary power source; any excess power (power which was not needed by the satellite electronics) was used to charge the storage batteries. In cases where peak-power requirements exceeded the power output of the solar cells, the batteries automatically supplied the difference. During orbital night, the storage batteries, which had a total capacity of approximately 11.7 ampere-hours, supplied all of the power required by the satellite. Precautions were taken to prevent internal circulating currents through the power-source interconnections and to preclude the total loss of power in the event that a short circuit occurred in one of the cells or batteries.

The storage batteries were electrically connected in three independent groups, each of which was connected to the solar-cell supply through its own current regulator to prevent an excessive rate of charge. The excess power was diverted through a bypass regulator to the main battery-output bus. During orbital night, when the solar cells were passive, silicon diodes in each series row of solar cells prevented the storage batteries from discharging into the solar cells. A similar function was performed by diodes included in each series row of solar cells located on the lateral surfaces of the satellite. Because of the satellite's rotation, each series row of solar cells on a lateral surface was alternately illuminated and then darkened. The diodes prevented the darkened solar-cell rows from loading the illuminated rows.

The storage batteries provided a relatively constant voltage across the solar cells, thereby isolating them from variations in the electrical load. The storage batteries were charged by the solar cells during orbital day and supplied all equipment loads during orbital night.

The TIROS V electrical power supply subsystem differed from previous TIROS subsystems in two respects. First, one-half of the silicon solar cells were of a gridded type. The use of the gridded cells increased the efficiency of the solar-energy converter by 8.25 percent. Second, the power supply protection units were repackaged in order to combine several circuits into a single unit. This repackaging was strictly a mechanical change and no electrical functions were affected.

B. PERFORMANCE EVALUATION

1. Energy-Balance Considerations

Before the launching of TIROS V, operational procedures for monitoring operation of the electrical power subsystem and for calculating the satellite's daily power requirements were prepared and published under the title "Operational Procedures for Power Supply Monitoring". The calculations of the satellite's daily power requirements along with the actual daily power used by the satellite were plotted for 356 days of TIROS V operation. This plot is shown in Figure XI-1.

During the 356 day period shown in Figure XI-1, the total daily power available varied between 1810 and 1090 ampere-minutes per day. It should be noted that the power base, i.e., the continuous power required by the satellite without programming, was less than 700 ampere-minutes per day. Figure XI-1 shows that this amount of energy was available throughout the satellite's operational life.

Since the infrared subsystem was disconnected just prior to launch, the practice of programming the satellite simply to expend excess energy was adopted in order to prevent excessive battery-charging currents. This practice was discontinued late in the satellite's operational life (Julian-day 291) when it became evident that the battery-supply voltage was dropping below the minus 26-volt lower operational limit. After the practice of programming to expend power was discontinued, the voltage level immediately returned to normal. Also contributing to the low voltage level noted on J-day 291 were the following factors: (1) interrogation of the satellite in total darkness, (2) deterioration of the solar-energy converter due to radiation damage and (3) aging of the storage batteries. An investigation disclosed that none of these factors by itself could have caused the low voltage level observed on TIROS V, but that all were contributory.

On July 9, 1962, twenty days after the launch of TIROS V, a high-altitude nuclear experiment was detonated over Johnston Island in the central Pacific Ocean. An investigation was performed to determine if there were any deleterious effects to the satellite resulting from this explosion.

As shown in Figure XI-2, the satellite did not come within 1000 nautical miles of the center of the blast until 114 minutes after the detonation. Although a downward trend can be noted in the voltage level of the satellite after day 30, the investigation disclosed that this is normal occurrence and cannot be completely attributed to nuclear radiation. Figure XI-3 shows the ratio of actual solar-cell voltage to calculated solar-cell voltage in the period before and after the Johnston Island detonation. This illustration indicates no definite trend due to radiation damage.

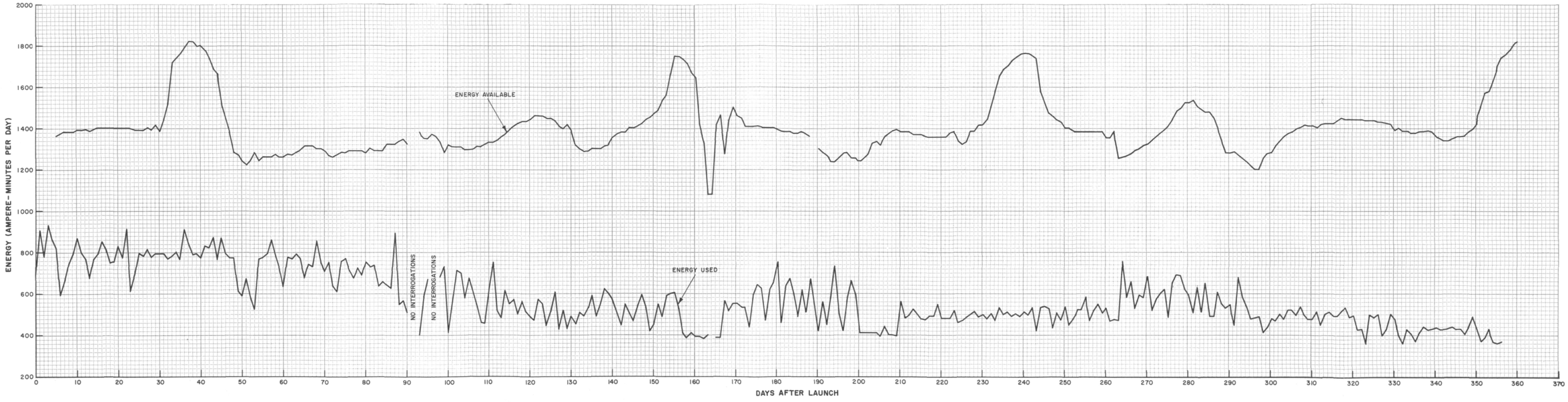

Figure XI-1. Predicted Energy Available and Actual Energy Used

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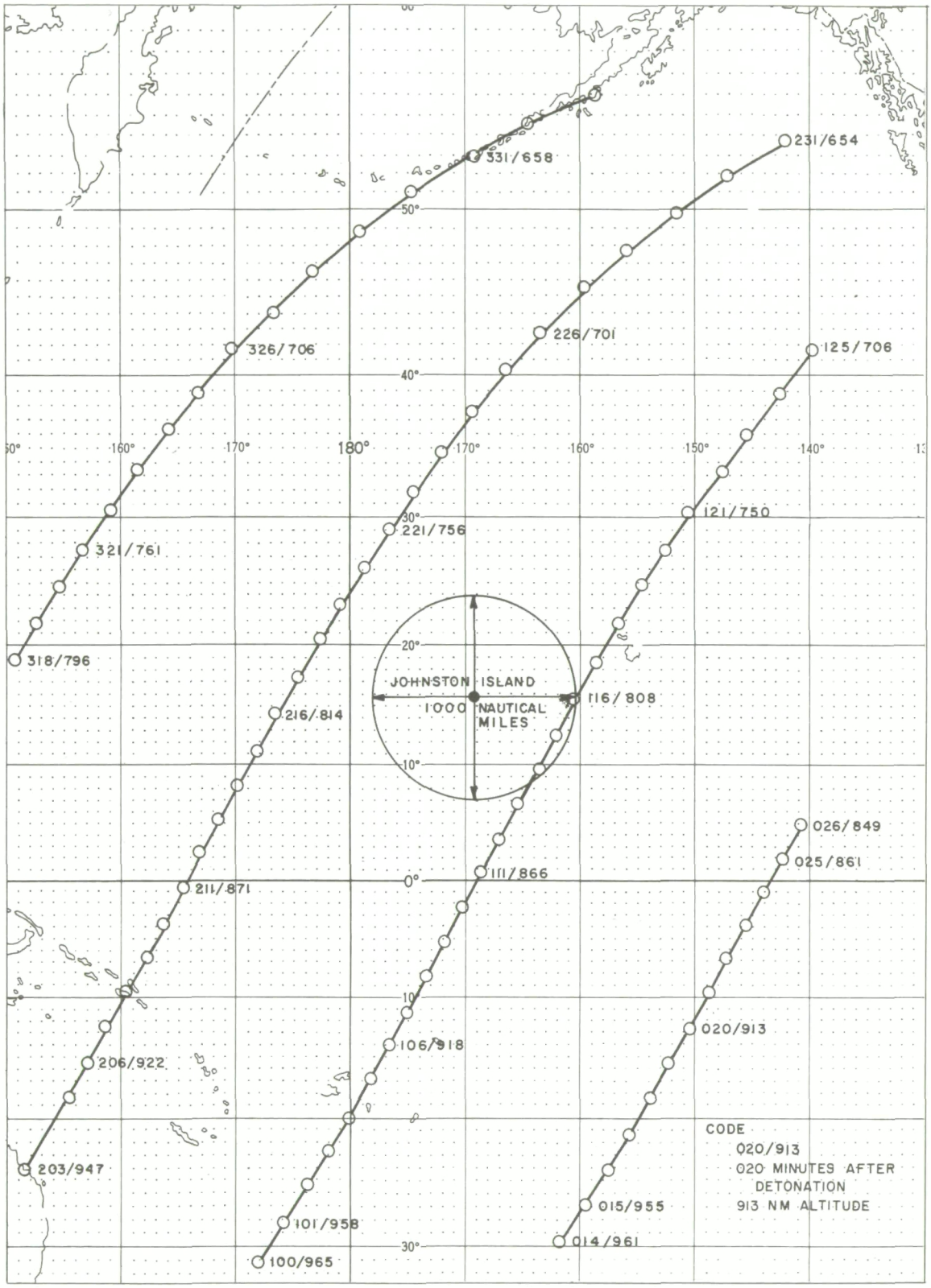

Figure XI-2. Ground Track of the TIROS V Satellite with Respect to Johnston Island on July 9, 1962

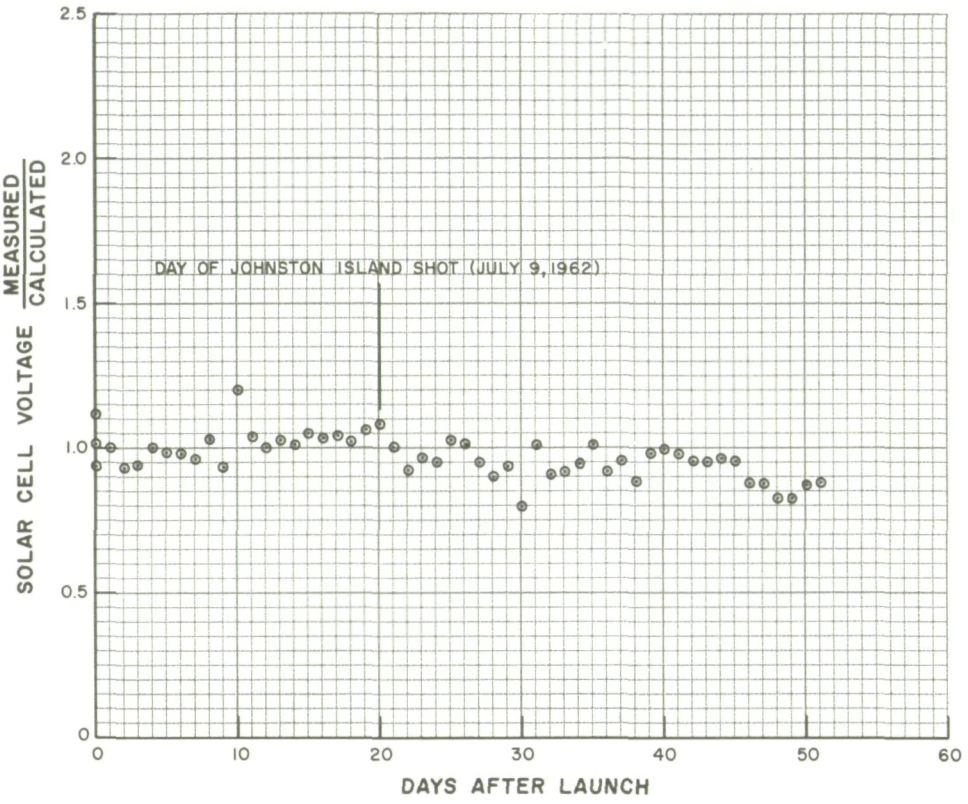

Figure XI-3. Ratio of Telemetered to Calculated Solar-Cell Voltage Before and After Johnston Island Detonation

2. Solar-Cell Telemetry

As on previous TIROS satellites, a group of 60 series-connected solar cells, comprising 12 five-cell "shingles" located on the top of the solar-cell hat, was electrically isolated from the power supply and loaded with a fixed resistance to provide a telemetry voltage from which solar-cell performance could be evaluated. The evaluation was performed by the use of the calibration charts shown in the final report and by the use of the thermistors located on the satellite.

A curve, showing the ratio of measured voltage to calculated voltage $\left(\frac{Vt}{Ve}\right)$ plotted against days after launch is presented in Figure XI-4. Initially, the calculated value of the voltage of the telemetry patch should be equal to the

actual voltage output. However, on the TIROS V satellite the initial value differed from the calculated value by a factor of 0.840. A combination of one or more of the following factors could have accounted for the ratio $\left(\frac{Vt}{Ve}\right)$ being less than 1.0:

(1) the calibration curves were in error,

(2) a high resistance developed in series with the solar-cell patch,

(3) a partial short developed in the solar-cell patch, or

(4) a reduction in solar cell output was caused by a burst of micrometeorites, or by a burst of charged particle radiation. (This possibility seems rather remote since the rest of the solar-cell array continued to function without exhibiting any degradation.)

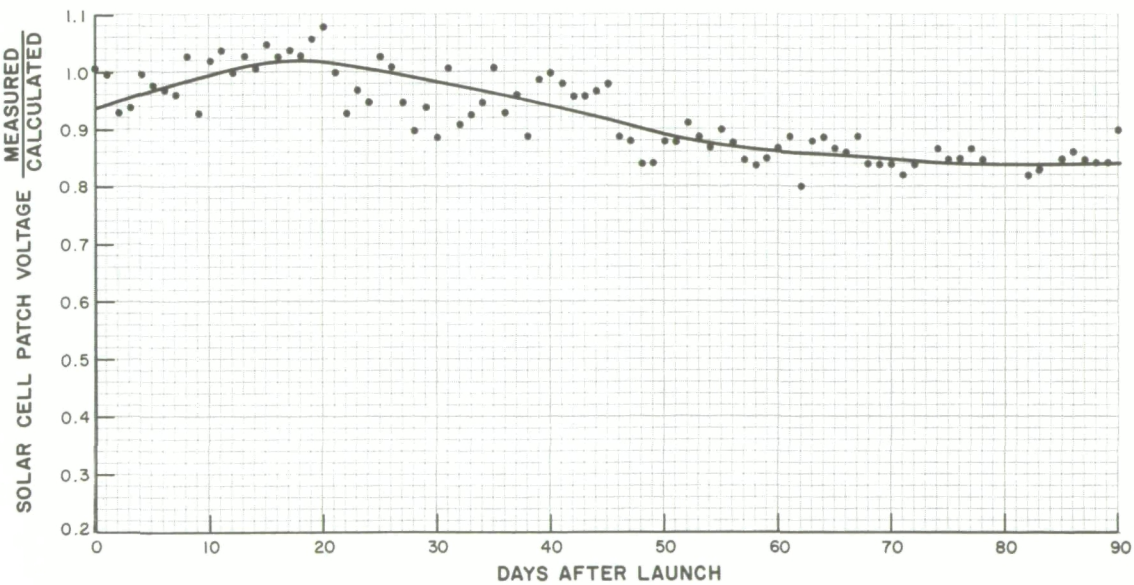

Figure XI-4. Ratio of Measured to Calculated Solar-Cell Patch Voltage for 90-Day Period Following Launch

On day 108, the solar-cell telemetry patch ceased to function and there has been no telemetered data from the patch since that time. There was no accompanying reduction in the solar-cell output or in the energy available to the system. It is believed, therefore, that a short circuit developed either in the patch or in its electrical wiring.

3. Storage Battery

a. Telemetered Data

The terminal voltage of each of the three rows of storage batteries, the input voltage to the 24.5-volt regulators, and the storage-battery temperatures were telemetered. A 22-volt zener diode in the voltage-sensing circuit provided telemetry of the voltages in the 22- to 32-volt range. The temperatures were sensed by a 0- to 40-degree C temperature sensor located on the battery package.

b. Evaluation of Telemetry Data

Figure XI-5 is a plot of the main-bus voltage during each day of the operational life of the TIROS V satellite. The main bus voltage was telemetered during both the playback and direct modes of camera operation, when the discharge rate of the batteries was maximum. The main-bus voltage was about 0.4 to 0.5 volt less than the individual battery-row voltages because of the voltage drop across the isolating diodes. The subsystem was designed to supply a minimum main-bus voltage of 25.5 volts to the voltage regulator under the most extreme conditions of battery temperature and instantaneous power drain, provided that the ampere-hour capacity of the batteries at +25°C had not been reduced by more than 15 percent. As shown by Figure XI-5, the main-bus voltage reached a maximum of 28.5 volts and a minimum of 25.8 volts during the operational life of the satellite. The later value was below the 26-volt limit and, in accordance with the written instructions, the cognizant AED engineer was notified. The immediate recommendation was to discontinue programming of the satellite solely for the expenditure of excess energy. This measure proved to be effective. The voltage returned to a normal level during Julian-day 292.

c. Storage-Battery Temperatures

A plot of battery temperatures telemetered during the operational life of TIROS V is given in Figure XI-6. Throughout this period, the telemetered battery temperature varied between +4.5°C and +32.5°C. The average temperature for the entire period was +11.8°C. These figures were in substantial agreement with the temperatures measured during the operational periods of the previous TIROS satellites. The main item of concern, the high-temperature limitation of the nickel-cadmium storage cell used in the TIROS satellites, is

Figure XI-5. Battery Voltage versus Days After Launch

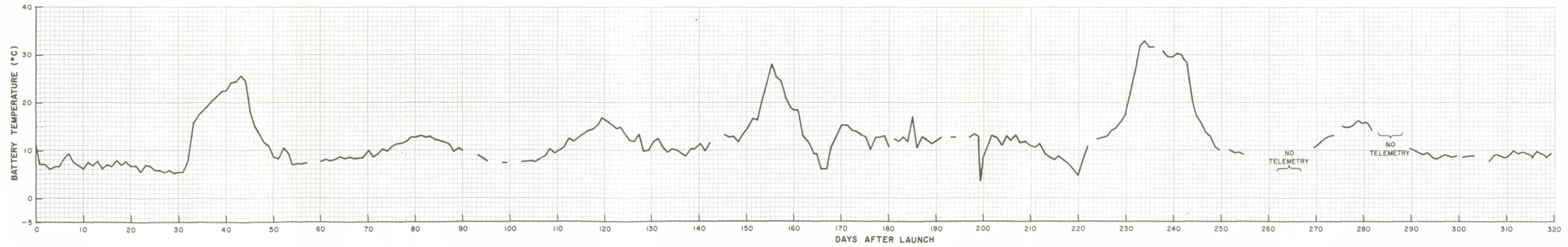

Figure XI-6. Battery Temperature versus Days After Launch

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discussed in detail in the TIROS I and II final reports. Briefly, the celluosic separator material employed in the cell suffers both physical and electrical deterioration when the cell is operated at or above +40°C for extended periods. The longevity of the storage batteries used on the TIROS satellites can be attributed, in part, to operating temperatures that never exceeded +33°C and that average only 11.8°C. In none of the TIROS satellites has the storage battery failed or in any way reduced the useful satellite life.

XII. SATELLITE THERMAL DESIGN

A. FUNCTION

As on the previous TIROS satellites, a passive temperature-control technique was used on TIROS V to maintain component temperatures within the allowable design extremes and to maintain solar-cell temperatures within the limits required for good conversion efficiency. The thermal design of TIROS V differed slightly from that of previous TIROS satellites in two respects: (1) an additional piece of thermal insulation (Rokide), covering a surface area of 11 square inches, was installed on the TIROS V hat, and (2) half of the TIROS V solar cells were of the "gridded" type, i.e., they were modified to provide lower internal resistance and thus higher efficiency.

The use of the gridded cells resulted in a decrease in the net absorptivity-to-emissivity ratio (α/ϵ) of the satellite; lower satellite temperatures were, therefore, to be expected. The TIROS V thermal design differed from the TIROS IV thermal design in an additional way: the thermal standoff placed between the satellite baseplate and the IR electronics unit on TIROS IV was not used on TIROS V.

A reduction in satellite orbital temperatures was anticipated as the result of the modifications described above. However, the temperature differences anticipated were not judged to be large. The variations were greatest at the perigee and apogee of the orbit, as the result of the slight eccentricity.

B. PERFORMANCE EVALUATION

The thermal response of the TIROS V satellite was entirely satisfactory. The mean component temperature from the day of launch, June 19, 1962, until May 6, 1963, the end of the useful operational life of the satellite, is given in Figure XII-1. Also given in Figure XII-1 is the percentage of the orbital period during which the satellite was illuminated by the sun. Figure XII-2 shows the temperature of the top of the satellite "hat" over the operational period and Figure X11-3 shows the satellite baseplate temperature over this same period.

Satellite component temperatures remained within the design limits of 0 and 50 °C throughout the period of satellite operation. Even during the periods of 100-percent sun time (days 35 to 40, 155 to 165, and 235 to 245) the maximum component temperature was 24° C, well within the design limits and well below the temperatures at which battery performance is affected.

As anticipated, all satellite temperatures were lower than on the previous satellites. The deviations of actual temperatures from the predicted temperatures ranged from 2 to 8°C. The generally lower temperature-time profile of TIROS V was attributable to the two changes mentioned above (added thermal insulation and the use of gridded solar cells over 50 percent of the solar-cell surface) and to additional factors resulting from a non-circular orbit and from non-operation of the IR electronics unit.

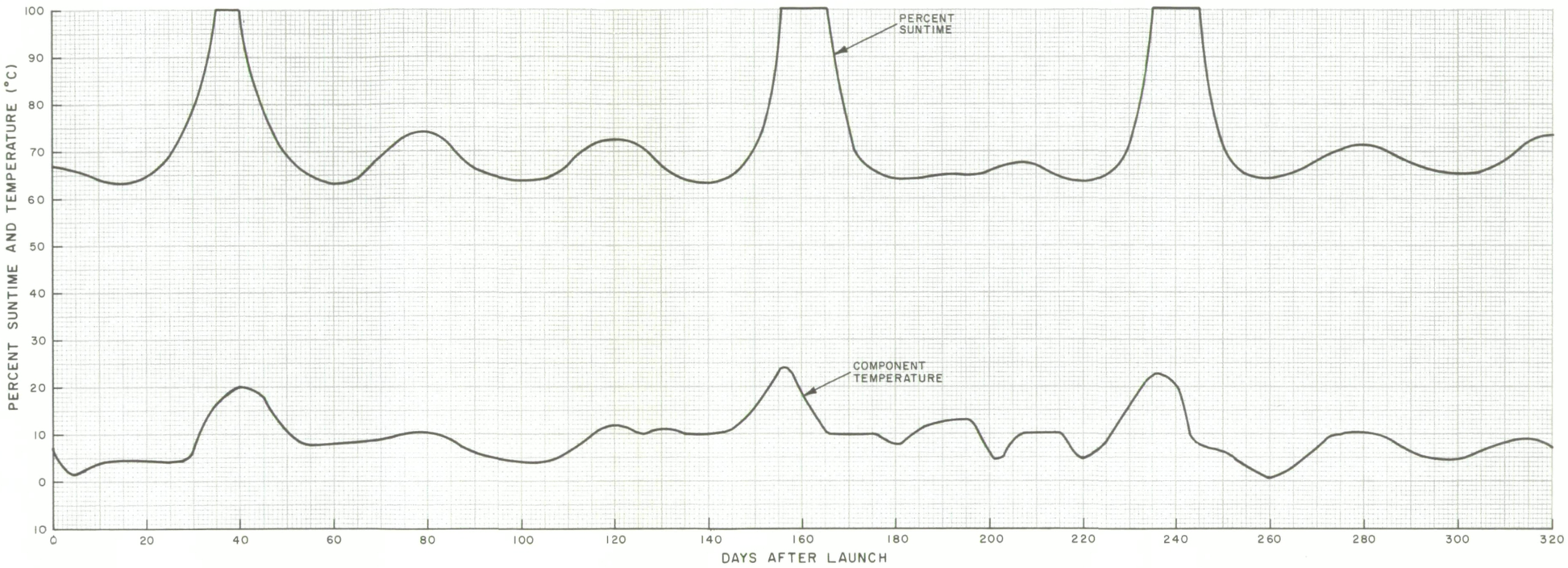

Figure XII-1. Mean Component Temperature and Percentage of Sun-Time versus Days After Launch

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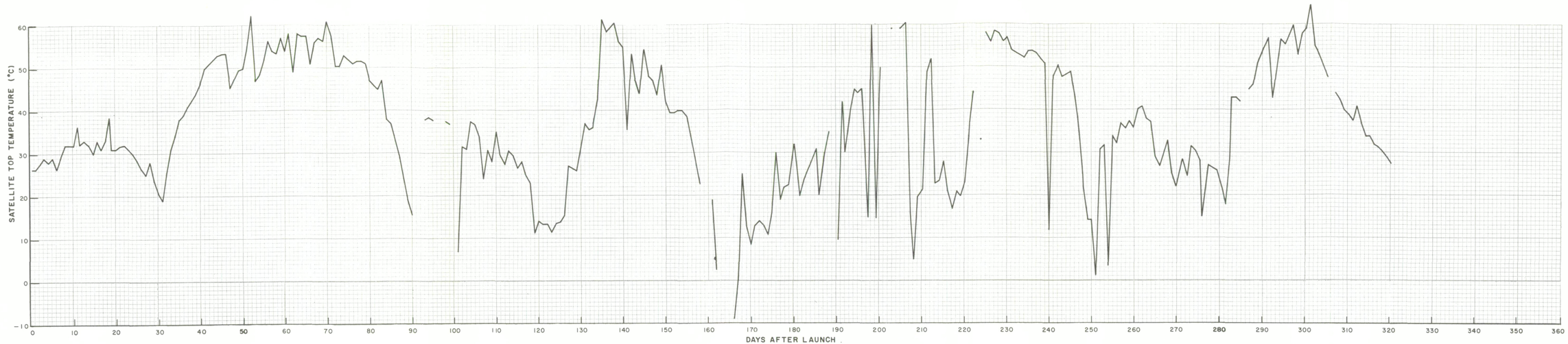

Figure XII-2. "Top" Temperature of Satellite versus Days After Launch

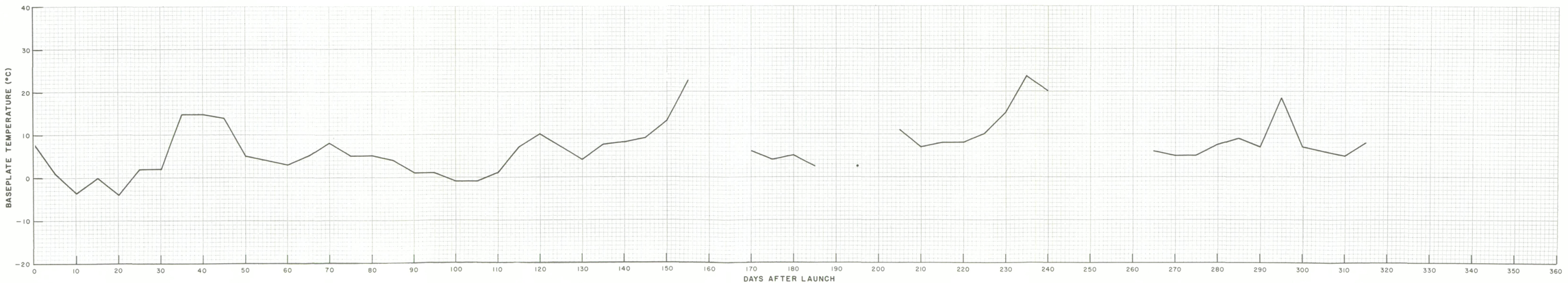

Figure XII-3. Baseplate Temperature of Satellite versus Days After Launch

XIII. GROUND SUPPORT

A. LAUNCH SUPPORT

1. Launch Operations

Launch operations for TIROS V comprised essentially the same test, checkout, and prelaunch calibration procedures used in preparation for the previous TIROS launchings. AED supplied members of the engineering staff for liaison and test support, and provided the equipment required for checkout of the satellite.

The prototype satellite T-2A, in which the TIROS V modifications had been incorporated, and the Go, No-Go Checkout Van, containing the satellite checkout equipment, were shipped from AED on May 28, 1962, and received at the Cape Canaveral Missile Test Area on May 31, 1962. Members of the AED engineering staff were present when the equipment arrived and proceeded immediately with the unpacking, inspecting, and installing of the equipment. Preliminary inspection and electrical checkout showed that the equipment had not sustained damage during shipment and that performance was normal.

Assisted by personnel of the NASA Data Laboratories (Launch Operations Division), AED staff members made the necessary antenna installations and successfully conducted the antenna checkout procedures. Antenna checkout was completed on June 1, 1962.

The RF interference checks were performed, with the prototype satellite mounted on the inert third-stage rocket. Satisfactory results were achieved and the tests were completed on June 5, 1962, as scheduled.

The flight-model spacecraft F-5 was received on the scheduled date, June 7, 1962. After the satellite had been checked and found free of damage, it was subjected to a complete electrical checkout and the five-channel IR radiometer was calibrated at ambient temperature.

A Task 4 checkout of the spacecraft was successfully completed on June 8, after which the spacecraft was released to DAC and transported to the spin-balance building.

On June 9, a second Task 4 procedure was performed, during which the IR transmitter did not remain on for the specified interval. Task 4 procedures were performed daily on June 10 through June 17. During this period, the IR subsystem again malfunctioned. The problem was investigated and corrected, after which the subsystem performed normally. On June 15, the spacecraft and third-stage rocket were mated with the launch vehicle and the F-3 day checks were satisfactorily accomplished. On June 17, during the daily Task 4 checkout, the IR subsystem again malfunctioned. Tests were conducted which indicated that the malfunction caused a high power drain of the spacecraft's power supply. Such a malfunction in orbit might cause early termination of the mission, and, consequently, at NASA's direction, the IR subsystem was disconnected from spacecraft power. The daily Task 4 checkout was then completed successfully. The F-1 day checks were successfully completed on June 18. The F-0 day checks were started in the evening of June 18 and continued into the morning of June 19.

The terminal count was started at 0425 A. M. EST on June 19 and continued until T-14 minutes when a problem developed in the ground helium supply for the second-stage of the launch vehicle. After this problem had been corrected, the count was resumed at 0700 A. M. EST and continued to lift off, which occurred at 0719 A. M. EST.

2. Orbital Data

The launch vehicle performed its mission on inertial guidance and preprogrammed events, injecting the spacecraft into an elliptical orbit having an apogee of 603.7 statute miles, a perigee of 366.7 statute miles, and an eccentricity of 0.02663. The anomalistic period of the orbit was 100.471 minutes and the orbit was inclined at 58.099 degrees to the earth's equator. The orbit-injection spin-rate was 120 rpm. The de-spin mechanism reduced the spin rate to a "safe-side" spin rate of 8.3 rpm.

B. COMMAND AND DATA ACQUISITION STATIONS

1. Introduction

Two primary Command and Data Acquisition (CDA) stations were included in the TIROS V ground complex, one located at the Pacific Missile Range (PMR), with installations at Point Mugu and San Nicolas Island, and the other at Wallops Island, Virginia. A secondary CDA station, located at the AED facility near Princeton, New Jersey, functioned as a back-up station for the Wallops Island station. Each CDA station comprised four basic sections:

(1) satellite command and control equipment,

(2) data-receiving components,

(3) data-processing and display components, and

(4) recording devices.

The functions of the primary CDA stations were:

(1) to transmit radio signals to the satellite for programming its operations and its data transmissions,

(2) to receive signals carrying the television, attitude, infrared, and telemetry data from the satellite,

(3) to extract data from the carrier signals,

(4) to record and identify the received data, and

(5) to relay the recorded TV, attitude, infrared, and telemetry data, along with station status reports, to the TIROS Technical Control Center, GSFC, Greenbelt, Maryland.

The back-up CDA station at the AED facility was equipped with the same functional units as the two primary stations. This station monitored the responses of the satellite to commands from the Wallops Island station, and assumed command responsibility for several orbits during the life of the TIROS V satellite when both CDA stations happened to be inoperative at the same time.

During the TIROS V operating period, the facsimile link that was established between the CDA stations and selected weather stations at key airports during the TIROS IV program was used extensively to transmit TIROS weather photographs. The results achieved were excellent, providing the basis for a system in which the dissemination of data more closely approaches the data-collecting rate of the satellites. Special radio circuits for international facsimile transmission of TIROS pictures were used again during the TIROS V program, also with excellent results.

2. Operational Evaluation

a. General

In general, the operational performance of the CDA stations was good. Following the institution of improved and consistent procedures for photography and photo-processing during the TIROS IV program, emphasis during the TIROS V program was placed on the formalization of the control methods and implementation of increased equipment reliability.

Prior to the launch of TIROS V, the decision was made to supply both primary CDA stations with identical equipment so that no cause would arise for the consideration of differences in design or in modes of operation as possible points of variation in the photographic processing procedures of the two stations.

To implement this decision, the stations were supplied with Macbeth TD-1000 Quantalog desitometers and EGG Mark VI sensitometers.

The Macbeth desitometers replaced the Eastman Kodak 1A densitometers used during the previous TIROS programs. The Eastman Kodak units were of the optical comparison type and were, therefore, subject to errors caused by differences in vision between different users.

The EGG sensitometers provided, in combination with the densitometers, a method of standardizing the photo-developing processes. Once this was obtained, the film exposed on the video monitor could be used to establish and to maintain the brightness of the kinescope display as outlined in the established procedure for brightness calibration of the TIROS TV cameras. (See Appendix B of the TIROS V final report.)

Throughout the TIROS V program the consistency of quality in the films received from both primary CDA stations proved the value of the new equipment and procedures.

b. Wallops Island Station

Because the equipment to be used during the TIROS V program was virtually identical to that used during the TIROS IV program, no extensive tests or check-outs were made at the Wallops Island ground station. The standard functional checks as noted in the TIROS V final report were made. The only change made to the equipment prior to the TIROS V launch was a modification made to the TV-FM demodulator in the vertical sync-separator circuit to reduce its susceptibility to noise. This change is described in detail in the TIROS V final report.

Monitoring of the satellite' s beacon signals was accomplished during launch; a Sanborn recording of the beacon signals was made by starting the recording at the receipt of the rocket lift-off signal. Spin-ups were also noted and recorded by the Sanborn recorder as well as by the tape punch.

During orbit 001, a spurious, differentiated pulse was noted in the Sanborn recording of the "sky-time" from the attitude indicator. This was later determined to be a sun glint on the lens. The pulse did not interfere with the data because both earth and sky periods are inhibited in the attitude-pulse selector.

The AGC voltages from the TV receivers remained at remarkably consistent levels during the first orbit, indicating that the antenna pattern distortion, which had occurred on TIROS III and IV as a result of the omnidirectional IR sensor arms, had been eliminated by modifications made to the arms.

The high-power ITA transmitter was used to command the satellite during the initial passes. The stability of the transmitter was improved by the use of the Collins transmitter as the exciter for the final stage of the ITA transmitter. No unprogrammed pictures were received during the initial passes, indicating that the receiver sensitivity of the satellite was satisfactory.

During the initial passes, the ground station equipment functioned normally with no occurrences of equipment malfunctioning. The only operational problems encountered during the TIROS V program were related to the antenna system and were caused either by equipment malfunction or by adverse weather conditions (i.e., wind or snow).

c. Pacific Missile Range Station

Operations at the PMR station prior to the TIROS V launch were very similar to those previously mentioned for the Wallops Island station, indicating the results of efforts to standardize operational and maintenance procedures. The modification of the TV-FM demodulator was incorporated and certain functional checks and calibrations were made prior to the launching of TIROS V.

Difficulty was encountered on the first three orbits in maintaining correct antenna orientation. This was attributed to inaccurate ephemeris data and poor operation of the autotrack circuits. After several circuit adjustments were completed and a marginal tube in the tracking electronics was replaced, autotrack operation was greatly improved and correct antenna orientation was achieved.

A loss of north-indicator data occurred during several of the initial passes because of a malfunction in the Friden tape punch. This was caused by a mechanical misalignment which was quickly located and corrected.

The excellance of the day-to-day performance of the PMR CDA station may be gauged by the high ratio of usable pictures obtained to total number of pictures taken by the satellite. The quality of the pictures ranged from good to excellent.

In addition, the infrequency of equipment malfunction or failure gave proof of an energetic and consistent maintenance program.

During the latter part of the TIROS V program, the Ampex tape transports began to exhibit excessive flutter due to wearing of the mechanical components. Replacement of these units was recommended.

The AT-36 tracking antenna underwent extensive modifications during March and April 1963. These modifications included the installation of a new drive system to provide a tracking capability in winds of up to 70 knots. In addition the antenna was releveled, repainted and recalibrated.

Several failures in the command transmitting system have been experienced at the station. The causes have been traced to the long transmission feed line and the matching section at the command antenna. Temporary repairs were made to these items on several occasions. The photographic laboratory facilities at PMR have been improved, and a long range plan has been instituted to provide better housing for these operations. The present van used for these purposes has been repaired and returned to service. However, plans for a larger and more adequate van, to be outfitted and located at the rear of the Navy Weather Station's main building, have been approved.

d. Princeton Back-Up Station

The Princeton ground station was called upon to perform its function as a back-up station twice during the operational life of the TIROS V satellite.

On the final occasion, during the period of June 19 to July 2, 1962, both CDA stations were unable to command the satellite for varying periods. The back-up station tracked 56 orbits and commanded the satellite during nine of them.

On the second occasion, during the period of August 9 through 11, 1962, both CDA stations were again inoperative. The Wallops Island station was inoperative because of repairs being made to the antenna. Meanwhile, continuing high winds at the PMR station had forced that station to suspend operations. The Weather Bureau was especially interested in continuing operations at this time because of a storm center located slightly north of Cuba and off the eastern coast of the United States. Four orbits were interrogated by the Princeton station, during which many meteorologically useful pictures were obtained.

On May 6, 1963, after TIROS V had ceased to transmit pictures to the CDA stations, the Princeton station was placed in operation to allow direct engineering analysis of the TIROS V malfunctions. During the period of May 6 to 8, the station recorded the attitude and telemetry data transmitted from the satellite while the satellite was commanded from the Wallops Island station. During the following week, the Princeton station assumed both command and programming responsibilities.

In spite of the fact that this series of interrogations was made without advance notice and without an opportunity for a station checkout, and additionally, that the station had not been used in satellite operations since the TIROS VI launching in September, the complete operation was carried out in a most satisfactory manner.

C. TIROS TECHNICAL CONTROL CENTER

1. Introduction

NASA Operations Division, Goddard Space Flight Center, Greenbelt, Maryland, functioned as the TIROS Technical Control (TTC) Center for the TIROS V satellite. The duties and responsibilities of the TTC Center were as follows:

(1) to accept, analyze, and catalog engineering reports on satellite and ground conditions;

(2) to accept, analyze, and transmit predictions concerning the locations of feasible photographic areas, the sequence of these areas, and the times when the satellite could be contacted by the ground stations;

(3) to accept daily programming recommendations from the U. S. Weather Bureau;

(4) to decide the actual sequence of operations for each day, after taking into consideration the condition of the power supply and performance of the satellite and ground stations;

(5) to prepare and transmit specific operating instructions and pertinent acquisition and picture-orientation information to the ground stations;

(6) to accept and review performance reports and significant telemetry data from the CDA stations;

(7) to select and transmit, immediately, instructions required for handling emergency situations; and

(8) to coordinate all TIROS V activities during the active life of the satellite in orbit.

2. Operational Evaluation

TTC prepared four alternative groups of programs for the first day of orbital operation. Program A was to be used if the launching was completely normal. Program B was to be used if separation from the third-stage rocket did not take place. Program C was to be used in case a satisfactory reduction in spin rate did not occur. Program D was to be used if the desired orbital parameters were not completely satisfied. Accordingly, with the occurrence of a satisfactory launch, Program A was used.

Satellite programming was restricted to some degree on the early orbits because of the occurrence of high nadir angles while the satellite was over illuminated portions of the earth. During later orbits, more favorable nadir angles occurred, and available power was the only restriction on programming. The procedures for monitoring and evaluating power-supply conditions were closely followed to assure efficient use of available power.

The control center activity, operating on a 24-hour-per-day, seven day-per-week basis, carried out its assigned tasks within the rigid time limits dictated by satellite schedules. An excellent working relationship was maintained with the CDA stations, various NASA groups, and the AED engineering and ground station personnel throughout this period.

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